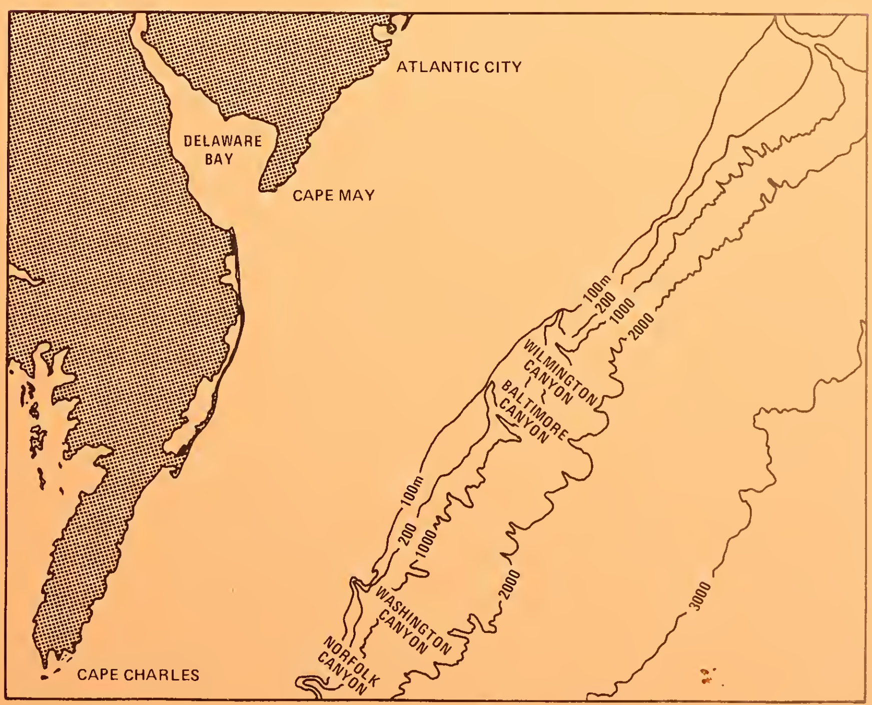
# Present and Recommended U.S. Government Research in Seafloor Engineering

July 1978




U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
Office of Ocean Engineering

# Present and Recommended U.S. Government Research in Seafloor Engineering

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July 1978

Prepared under Contract number 03-7-038-739 (1F)



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Washington, D.C. 20402

Stock No. 003-019-00044-6

TABLE OF CONTENTS

Appendices

# EXECUTIVE SUMMARY

The purpose of this report is (1) to summarize federal agency research, development, and funding sources in seafloor engineering and (2) to present recommendations and priorities for the future federal funding of research in seafloor engineering. The recommendations and priorities are intended to be useful to all federal agencies concerned with seafloor engineering, although the degree of applicability may vary in accordance with agency mission objectives.

Seafloor engineering was defined for this report to include only that part of marine geotechnics that is directly concerned with the seafloor; environmental loads and driving forces are excluded from the report.

The research, development, and identified funding activities of four National Oceanic and Atmospheric Administration units, the Department of Energy, the National Science Foundation, the U.S. Geological Survey, and two units of the U.S. Navy are presented. Minimal seafloor engineering research and development activity was identified in the Environmental Protection Agency, the U.S. Army Corps of Engineers, and the U.S. Coast Guard; hence, almost no information is provided.

The recommended research plan and priorities that are presented evolved as follows. Recommendations contained in the National Research Council's report on seafloor engineering and in reports prepared by a number of other committees were focused to define more specifically identified needs and priorities in civil seafloor engineering research. A draft plan of research was prepared from the prior documents and from the consultant's perception of the U.S. national needs. The new plan, together with five questions relevant to the plan, was mailed to 145 practitioners of seafloor engineering in industry, academia, and government. A document was prepared from the responses that provided the principal input to a review meeting attended by invited senior specialists from industry, academia, and government. At the review meeting the research plan contained in the input document was critically reviewed and modified. The resulting recommendations, adopted by all of the participants, were grouped into the following three categories: soil properties and behavior, geotechnical environmental hazards, and soil-structure interaction problems. Each recommendation in the three categories was assigned to one of three general priorities: high, medium, and desirable. Recommendations were left unranked within each priority group. A draft copy of this report was circulated to each of the review meeting participants for review before the present final report was submitted to the NOAA Office of Ocean Engineering for publication.

The recommendations for federal funding of seafloor engineering research are listed in the following summary:

Priority 1: High

Soil Properties and Behavior

1. Shear strength (short- and long-term; undrained and drained); creep strength; cyclic strength; deformation characteristics; and bearing capacity
2. Strength changes, including liquefaction, and stress-strain behavior of soils under dynamic and repeated loading, particularly under long-term cyclic loading
3. Development of improved soil sampling techniques to minimize sample disturbance and development of improved procedures for the quantitative assessment of sample disturbance and its causes
4. Measurement offshore of both microseismic activity and strong motion activity in areas of concern
5. Pore pressure and state of stress, particularly in situ and in areas of concern

Geotechnical Environmental Hazards

1. Slope stability
   Detection of submarine landslides, slumps, scarps, and faults, including location, age, and size; site surveys for assessment of potential failure of sediments under conditions of earthquake and other stresses; determination of the probability of repeated movements and the rates of movement; and prediction of soil loading on structures at and just below the seafloor resulting from seafloor instability
2. Liquefaction
   Liquefaction potential and strength loss due to pore-pressure buildup under cyclic loads; effects on the degradation of shear properties; techniques for evaluating general and localized liquefaction, caused by waves or by seismic loading, and its effects on the capacity of footings and piles and the stability of pipelines
3. Faults and faulting
   Techniques for identifying and evaluating the magnitude of probable seafloor fault movement, frequencies, and total displacements resulting from earthquakes that should be anticipated; mechanisms and consequences of fault rupture; and evaluation of the probability of fault movement

Soil-structure Interaction Problems

1. Investigation of the performance of laterally-loaded piles in soils, with emphasis on fine sands and silts (static, slow cyclic,

and dynamic or seismic loadings)
2. Developing loading and response data to improve the design of mudslide-resistant structures
3. Critical evaluation leading to the solution of "rational" or pseudo effective stress vs. empirical correlation methods for the analysis and design of axially-loaded piles
4. Performance monitoring of seafloor foundations

Priority 2: Medium

Soil Properties and Behavior
1. Measurement of free-field ground motion and correlation with concurrent, measured structural response
2. Stress-strain relationships, including state of stress
3. Compressibility characteristics
4. Time-consolidation and permeability
5. Quality, quantity, and state of gas present, particularly in situ
6. Fossil permafrost in seafloor soils
7. Statistical characterization of the geotechnical properties of specific seafloor soil types
8. Evaluation of geophysical and remote sensing techniques for site characterization: definition of soil types, their geometrical boundaries, and their geotechnical properties
9. Disturbance of granular soils under wave action, with particular relationship to outfalls and pipelines

Geotechnical Environmental Hazards

Consideration of the causes and consequences of scour and fill, including sand waves, both on the open seafloor and in association with structures

Soil-structure Interaction Problems
1. Large-displacement lateral-load performance of pile groups (static, slow cyclic, dynamic or seismic loadings)
2. Estimation of allowable lateral and axial pile support in calcareous sands, particularly those composed of crushable tests or shells
3. Determination of sediment trafficability, with emphasis on pipelines, mining, and cables
4. Behavior of gravity structures founded on different types of soils under wave loading and/or seismic excitation
5. High capacity (>100 kip or 4.5 Mg deep-sea anchorages, including coral and rock)

Priority 3: Desirable

Soil Properties and Behavior

1. Classification and consistency, unit weight, and mineralogical composition
2. Composition of pore-water electrolyte (salt content and its effect on geotechnical properties)

Geotechnical Environmental Hazards

Evaluation of the depth, extent, and frequency of ice gouging of the seafloor

Soil-structure Interaction Problems

No priority 3 recommendations

Each research category and subject within each category is believed to be self-explanatory. The review meeting participants proposed that while most of the soil-structure interaction problems could be cosponsored and funded by both industry and government, other problems might be undertaken by one or more companies or by one or more governmental agencies. It was intended by the participants that within the soil properties and behavior and geotechnical environmental hazards categories the recommendations were primarily intended for industrial and academic research to be funded by agencies of the U.S. government.

The need for a data transfer system was discussed at the review meeting. The participants questioned the cost effectiveness of accumulating geotechnical data in centralized data centers. They were more in favor of publishing geologic information on near-surface soils, which could be used in a preliminary way to estimate the range of geotechnical parameters, rather than data banking geotechnical data. The participants suggested that geotechnical data accession and dissemination be undertaken by data centers only if it were fully justified by users.

## INTRODUCTION

A report on Seafloor Engineering: National Needs and Research Requirements was developed under the auspices of the Marine Board of the National Research Council and published in 1976 by the National Academy of Sciences. This report recommended a comprehensive program of seafloor engineering research, but insufficient detail was provided to translate the recommendations into federal funding initiatives. A number of other committees and organizations in the past two years also have recommended seafloor research programs or objectives for federal funding. A list is given in Appendix A. There is reasonably consistent agreement in all of these reports as to what research is required in the national interest.

The present report has two primary objectives: (1) to focus these prior efforts and define more specifically identified needs and priorities in civil seafloor engineering research, and (2) to summarize briefly federal research and development, as well as funding sources, in seafloor engineering as of February 1978.

The National Advisory Committee on Oceans and Atmosphere (NACOA) in 1974 recommended that there be an agency responsible for civil ocean engineering research and development within the Federal Government and that the National Oceanic and Atmospheric Administration (NOAA) would be the appropriate agency. The NOAA Office of Ocean Engineering, (OOE) was established with the basic mission to serve as the civilian focal point for responding to user requirements for ocean engineering and technology and for obtaining commitments of resources for development in these areas. Seafloor engineering was identified by OOE personnel as a priority area project, since few of the recommendations contained in the NRC Seafloor Engineering report had yet been implemented by agencies of the U.S. government.

Seafloor engineering has been defined for the purposes of this report to include only that part of marine geotechnics that is directly concerned with the seafloor. Environmental loads and driving forces, such as waves, ice, etc., will be included in other programs being developed by the Office of Ocean Engineering and other governmental agencies; they will not be considered further in this report. While no water-depth limit has been applied in this report, major emphasis may be inferred to be on the U.S. continental margins.

It was originally intended that a seafloor engineering workshop would be held to identify and assess specific user requirements for seafloor engineering, to translate these requirements into program elements, to establish short- and long-term priorities, and to determine program elements most appropriate for federal support. The workshop approach was modified at an early stage in favor of proceeding as follows: (1) to draft a proposed plan based on the recommendations contained in previous reports prepared by numerous committees and organizations and the consultant's perception of the U.S. national needs, (2) to circulate the draft plan to a large number of representative practitioners of seafloor engineering in industry, academia, and government, and (3) to hold a small meeting attended by invited senior specialists in seafloor engineering representing industry, academia, and government for the purpose of reviewing responses to the circulated draft plan, recommending a research plan, and deciding on priorities. Professors Hudson Matlock and Adrian Richards were retained as consultants to the OOE to provide assistance in this seafloor engineering study.

An important aspect of the OOE development of a seafloor engineering plan was to have it equally useful to all federal agencies concerned with seafloor engineering. It was envisioned that some program elements of the plan would be addressed by the OOE. Others would be considered in programs and activities of the U.S. Geological Survey (USGS), Department of Energy (DOE), National Science Foundation, U.S. Navy, and other agencies. Still others might best be accommodated through the cooperation of two or more agencies. From the beginning, representatives from the USGS, DOE, Navy, and other agencies were contacted and involved; particularly close liaison was maintained with USGS personnel.

## EXISTING AND PROPOSED FEDERAL SEAFLOOR ENGINEERING PROGRAMS

One of the objectives of the NOAA Office of Ocean Engineering was to learn what seafloor engineering research was being conducted within the federal government for the purpose of minimizing duplication and assessing prospects for cooperative research funding between agencies. Emphasis has been placed on those agencies having programs in which external funding and/or cooperative interaction with industrial or academic organizations occurs. Statements were prepared for this report by representatives of four NOAA units, the Department of Energy, the National Science Foundation, the U.S. Geological Survey, and two units of the U.S. Navy.

A number of federal agencies are not included in this report. Within the Environmental Protection Agency, there appears to be minimal seafloor engineering activity at present in the Office of Radiation Programs, Ocean Programs Branch, and in the office of the Principal Engineering Science Advisor. The U.S. Army Corps of Engineers presently does not have a seafloor engineering program seaward of the surf zone. Seafloor engineering in the Civil Engineering and Ocean Engineering divisions of the U.S. Coast Guard presently is restricted to dock construction, which is managed within the organization. Within the Navy Ocean Research and Development Activity (NORDA), limited seafloor engineering is conducted within the Naval Oceanographic Laboratory and the Ocean Research Office. Studies in the Oceanographic Laboratory are primarily in-house efforts emphasizing geotechnical properties of deep-sea soils and their geoacoustic properties and including laboratory compressability and shear-wave investigations at high pressures. The NORDA Ocean Research Office is colocated with the Office of Naval Research Ocean Science and Technology Division, whose use of external seafloor engineering funding has been restricted to a recently completed investigation of the feasibility of using gamma ray and neutron moderation equipment in situ, the development of ocean-bottom seismometers, and shear-wave studies.

The following summaries, discussing existing and proposed federal seafloor engineering programs, were written by the listed authors for inclusion in this report.

## NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

### Atlantic Oceanographic and Meteorological Laboratories by Richard H. Bennett

Introduction.--NOAA's Marine Geotechnical-Rational Use of the Seafloor (RUSEF) Program of the Atlantic Oceanographic and Meteorological Laboratories (AOML) Marine Geology and Geophysics Laboratory is an ongoing research effort having its inception in 1966 with investigations that were focused on deep ocean basin research. These early studies were concerned with the geotechnical or mass physical properties of deep sea submarine sediments. Early research was concerned not only with regional aspects of the North Atlantic and Pacific Basin sediments but also with the geotechnical properties of selected marginal sea deposits and site-specific areas. During the early 1970's a major effort was given to a comprehensive evaluation of the geotechnical program carried out aboard the Glomar Challenger, Deep-Sea Drilling Project, and as part of this project, research was carried out on the geotechnical properties of deep cores recovered from the Panama Basin and eastern equatorial Pacific. The first shear strength measurements performed on carefully selected DSDP cored sediment were carried out during these investigations on Leg 16.

During the early and middle 1970's emphasis in marine geotechnical research at AOML changed from deep ocean basin studies to a major research effort devoted to the investigation of the U. S. Atlantic Continental Margin and site-specific areas of the Mississippi Delta. In response to the nation's increasing interest in offshore petroleum reserves and the intimately-related engineering activities associated with the recovery of these resources, AOML's Marine Geotechnical-Rational Use of the Seafloor Program responded to basic and fundamental research needs, required in this hostile environment.

AOML's Marine Geotechnical-RUSEF investigations are directed towards an understanding of the important geological processes active on the continental margin, of seafloor geotechnical properties, and of stability-instability factors and conditions that are extremely relevant to man's activity, ultimate safety, and impact on the marine environment.

Clearly, the nation's increasing demands for offshore natural resources have stimulated considerable activity in numerous areas of the continental shelf, slope, and rise. Present and future plans for the emplacement of structures on and within the seafloor deposits (drilling platforms, pipelines, storage tanks, and atomic reactors) and the removal of seafloor deposits and the dumping of waste materials, dictate the urgent requirement for an understanding of the geotechnical properties, geological processes, and potential geological hazards associated with continental margin deposits. These aspects must be assessed and elucidated to predict with confidence (1) the potential natural environmental hazards to man-placed structures on the seafloor, and (2) the potential environmental stresses placed on an offshore area due to the emplacement of structures, the removal of natural resources, and the dumping of waste materials.

General Areas of Investigation and Goals.--The Marine Geotechnical-RUSEF Program combines research efforts with major emphasis placed on a multi-interdisciplinary approach to problem solving and investigations, drawing from such disciplines as geology, geophysics, chemistry, physical oceanography, soil mechanics, and mapping. Research efforts are focused on the western Atlantic Continental Margin from New England to the Bahama Platform and the Gulf of Mexico. Bywords of this program are processes, mechanisms, and soil properties related to the sedimentary framework and seafloor stability-instability on the continental shelf, slope, rise, and abyssal plain. The overall purpose of these studies is to provide geotechnical information for rational decision-making regarding intelligent use of the seafloor.

More specifically, the program studies are concerned with those processes taking place today that influence the erosion, transport, and deposition of sediment along the continental margin. Studies are made of the older sedimentary sequences, through geophysical techniques and correlation with existing deep bore-hole data, to understand the depositional history of this geomorphic province. Study is also made of submarine canyons and their role in the transport of sediment from coastal areas to the deep sea. The program also deals with slope stability and gravitational processes, such as slides, slumping, creep, and turbidity flows. These studies are directed towards gaining an insight into processes associated with sediment mass movement and the delineation of "key" mechanisms and soil properties associated with and/or responsible for submarine sediment stability-instability.

Geotechnical studies are designed to provide an understanding of regional and site-specific patterns, variability laterally and with depth below the mudline, and to characterize seafloor deposits

both on a local and a broad scale in terms of the mass physical properties. Of paramount importance also is an understanding of certain seafloor deposits in terms of their behavior under not only static but also dynamic conditions; specifically, the response of the soils and pore pressure during active storm periods. These studies provide a better understanding of sediment stability-instability and potential mass movement for a diversity of environments and soil types particularly in the regions of national interest. Ultimate goals are the capability of assessing cause and effect relationships of seafloor stability-instability factors, the development of reliable predictive models of sediment movement, and the assessment of potentially unstable areas on the continental margins relating to currents, waves, and gravity-induced forces.

Specific Areas of Investigation and Accomplishments, East Coast.--Studies presently focus on the U. S. east coast continental margin between Cape Cod and Cape Canaveral (Fig. 1). These studies were initiated in 1974 and to date over 300 bottom sediment samples have been collected including piston cores, hydroplastic cores, and grabs recovered from canyons and transects perpendicular to the margin. Core transects normal to the margin were taken at approximately 80 km intervals to determine sediment characteristics and geotechnical properties. Sediment cores were also collected on the upper rise to assess the sediment and geotechnical properties and regional patterns of these seafloor deposits. Selected cores are being studied in cooperation with researchers of the University of South Florida, Duke University, Oregon State University, Florida International University, Florida State University, and Texas A & M University. Approximately 9,000 nautical miles of seismic reflection and 3.5 kHz profiles were run parallel to the margin on the outer shelf, upper and lower slope, upper rise, and in selected canyons and intercanyon areas (site-specific areas) to determine sediment distribution and processes that are presently active and those processes that were active in the geologic past. Detailed geophysical studies, bottom sampling in selected canyons, submersible observations, and current meter data, are being integrated to determine processes active in the canyons and the role of the canyons in the transport of material to the deep sea.

The suite of data collected on the continental margin, both regionally and in site-specific areas on the slope, rise, and in specific canyons, includes: narrow-beam echo soundings (NBES), 3.5 kHz and seismic profiles, bottom samples (cores and grabs), bottom photographs, and current meter data.

In addition to the regional studies and submarine canyon investigations, detailed site-specific areas are being studied on the slope,

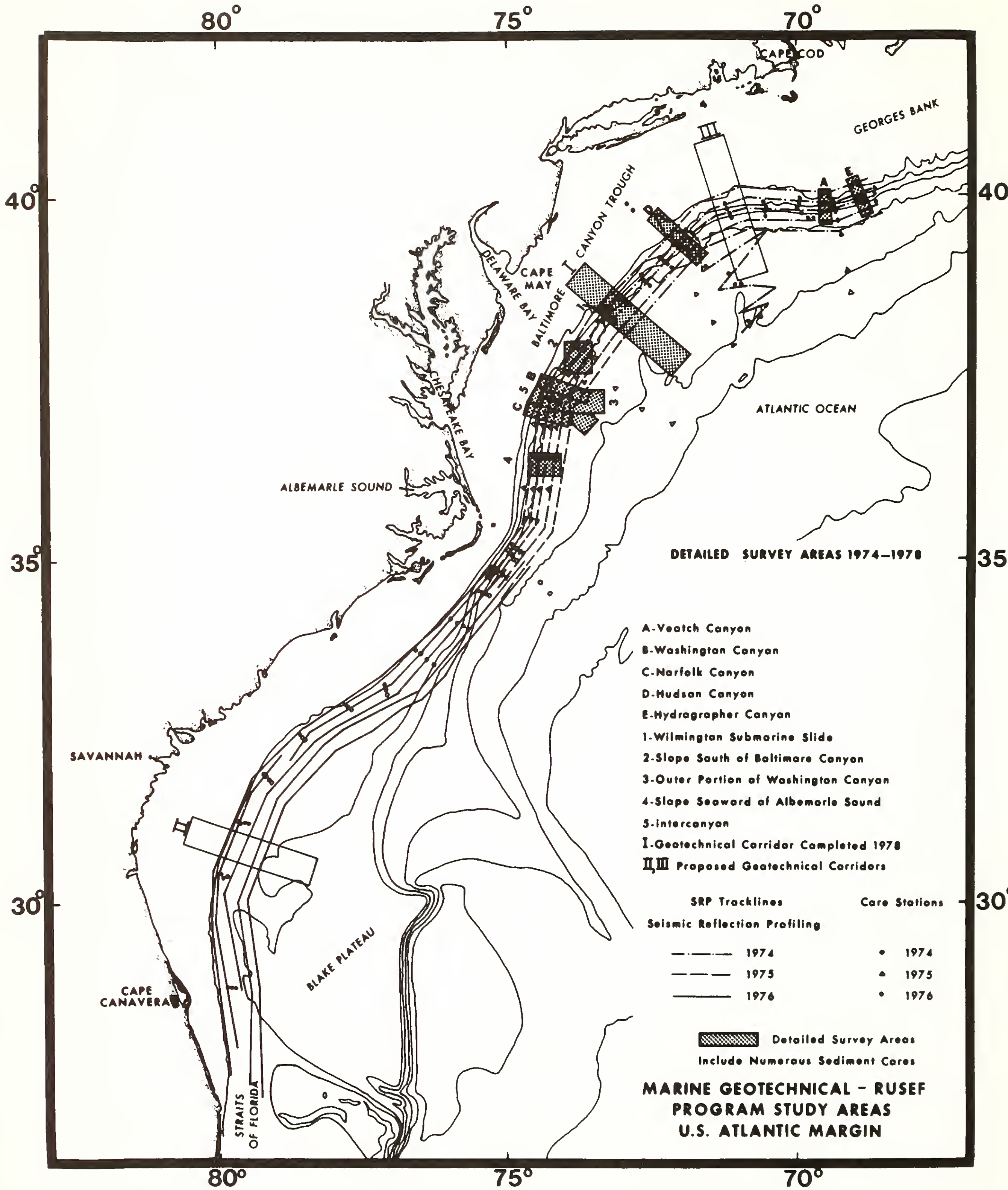
80°
75°
70°
40°
35°
30°
CAPE COD
GEORGES BANK
CANYON TROUGH
CAPE MAY
DELAWARE BAY
BALTIMORE
CHESAPEAKE BAY
ALBEMARLE SOUND
ATLANTIC OCEAN
SAVANNAH
CAPE CANAVERAL
BLAKE PLATEAU
STRAITS OF FLORIDA
DETAILED SURVEY AREAS 1974–1978
A-Veatch Canyon
B-Washington Canyon
C-Norfolk Canyon
D-Hudson Canyon
E-Hydrographer Canyon
1-Wilmington Submarine Slide
2-Slope South of Baltimore Canyon
3-Outer Portion of Washington Canyon
4-Slope Seaward of Albemarle Sound
5-Intercanyon
I-Geotechnical Corridor Completed 1978
II,III Proposed Geotechnical Corridors
SRP Tracklines
Seismic Reflection Profiling
Core Stations
1974
1975
1976
Detailed Survey Areas
Include Numerous Sediment Cores
MARINE GEOTECHNICAL - RUSEF
PROGRAM STUDY AREAS
U.S. ATLANTIC MARGIN

FIG. 1

northeast of Wilmington Canyon, south of Baltimore Canyon and seaward of Albermarle Sounds, and on the upper rise between Washington and Norfolk Canyons. These areas are being studied in terms of their geological, geophysical, sedimentological, and geotechnical characteristics. Among some of the more important questions being addressed are: seafloor stability, geological history and stratigraphy, geological and sedimentological processes, oceanographic processes, geotechnical properties variability, and sediment characteristics of the surficial submarine sediments and sedimentation patterns.

In response to offshore engineering needs defined in the 1976 report of the Committee on Seafloor Engineering, National Research Council, there has been initiated in the Marine Geotechnical-RUSEF program detailed investigations in a geotechnical corridor seaward of Cape May off the coast of New Jersey and northeast of Wilmington Canyon (Fig. 1). This 30 x 70 nautical mile corridor crosses the Baltimore Canyon Trough where oil exploration is presently underway. Field work was initiated in 1977 during which seismic reflection, 3.5 kHz, NBES profiles, and core samples were collected. The remainder of the geophysics and coring was completed during a cruise in May 1978. This corridor is considered to be representative of the continental margin between Hudson Canyon and seaward of Cape Hatteras. Two additional geotechnical corridors are planned for future years: one seaward from Rhode Island will provide data on a previously glaciated portion of the continental margin; the other corridor seaward of Savannah off the Georgia coast will cover part of the Blake Plateau and the Georgia embayment where substantial cycles of erosion and deposition have occurred. Each selected corridor is considered to be representative of the respective offshore regions, and the studies are expected to provide representative parameters of the geophysics, stratigraphy, sediments, geology, bathymetry, and geotechnical properties characteristic of the selected areas.

To date approximately 95% of the cores and bottom samples held at AOML have been described and analyzed and the majority of the geophysical data have been reduced and preliminary interpretations completed. Several reports have been published and others are in press or in preparation.

Gulf of Mexico.--AOML's geotechnical studies in the Gulf of Mexico have been site-specific in selected areas of the Mississippi Delta and problem oriented. Clay fabric and geotechnical properties investigations were initiated in 1972 in cooperation with Texas A & M University, Department of Oceanography, personnel. Studies are directed towards an understanding of the fabric characteristics of various Mississippi pro-delta muds and the relationships of the

clay fabric to the geotechnical properties. Of fundamental significance is that clay fabric, or particle-to-particle relationships, plays an important role in determining the ultimate response of a sediment to static and dynamic loads and is important as well in determining the ultimate nature of the mass physical properties of the electrolyte-gas-solid system of seafloor deposits.

More recent developments initiated in 1975 at AOML have demonstrated the criticality of pore-water pressure measurements in the determination of excess pore pressures as applied to the engineering properties of seafloor sediments. In response to this need, AOML has developed shallow-water piezometer probes and is conducting in situ experiments with these instruments in the Mississippi Delta. The purpose of these experiments is to measure and monitor sediment pore pressures under static and dynamic (during storm periods) conditions to assess the magnitude and importance of these pressures and pressure perturbations to sediment stability-instability in high porosity, low shear-strength soils. Initial results at three sites have revealed significant excess pore pressures in these sediments. A long-term experiment showed a definite response of the pore waters to the influence of Hurricane Eloise.

AOML's Mississippi Delta studies have been carried out in cooperation with Texas A & M University and during specific studies with Louisiana State University, U. S. Geological Survey, Lehigh University, and Sandia Corporation.

Current and Future Plans.--AOML researchers actively involved in the Marine Geotechnical-RUSEF Program and cooperating scientists and engineers from various institutions plan to continue investigations on the U. S. Atlantic Continental Margin in the geotechnical corridors and in site-specific areas of particular interest. In-depth studies are underway into the problems of seafloor stability, geologic processes, and the characterization of seafloor deposits in terms of their geotechnical properties, morphology, and geologic setting.

A continuation of site-specific studies is planned for 1978 and ensuing years in the Mississippi Delta region and the Gulf of Mexico. Investigations will focus on specific geotechnical problems of clay fabric, pore pressures, sediment stability, and the in situ state of stress. Plans are for better piezometer data acquisition systems suitable for collection of data under severe storm and related environmental conditions which are considered acute periods in the ultimate stability of submarine sediments. Detailed studies of clay fabrics from samples obtained using a newly developed pressurized core barrel designed and fabricated by Texas A & M are planned for 1978-79.

Program review booklets giving details of the Marine Geotechnical-Rational Use of the Seafloor Program are available through the NOAA-AOML. Personal communications with AOML staff are encouraged.

National Sea Grant Program by Richard C. Kolf

The purpose of the National Sea Grant Program is the development and wise use of marine resources. This is addressed by three principal activities, i.e. research, education, and advisory services, which are conducted through grants mainly to academic institutions. An effort is made to develop institutions which will have a broad and balanced program in which all three types of activity are harmoniously united and focussed on priority regional marine resource problem areas. Most of the National Sea Grant Program budget is devoted to these institutional programs. Individual investigators at institutions which do not have these broad programs are eligible to submit proposals, however, and the present level of support for such individual project support is approximately $1.5 million.

To date, the level of effort in the area of seafloor engineering has been small. This is, of course, a function of proposal pressure, and the regional priorities established by the active institutional programs. During FY 1977 two projects were supported in this area, both conducted at Massachusetts Institute of Technology. These were a study of the cone penetrometer and an effort to develop a method for offshore geotechnical risk analysis.

Office of Ocean Engineering by Samuel Sigmund

The Office of Ocean Engineering (OOE) is a primary organizational element of the National Oceanic and Atmospheric Administration. Its basic mission is to serve as the civilian focal point for responding to user requirements for ocean engineering and technology and for obtaining commitments of resources for development in these areas.

The OOE is responsible for responding to the ocean engineering requirements of federal agencies, state and local governments, and private civilian organizations and individuals, for initiating and encouraging development programs for advancing ocean engineering and technology, for supporting NOAA programs to gather, archive, and disseminate pertinent data, and for maintaining liaison with other national and international ocean engineering activities to maintain awareness of current technology and to encourage cooperative research, development, and exchange of information.

Specific objectives of the ocean engineering program are: (1) To promote timely development of ocean engineering capabilities to effectively and responsibly utilize the resources and benefits offered by the ocean environment. Technology development is directed toward providing tools for resource assessment and monitoring and for determing the environmental factors affecting ocean engineering activities. (2) To provide manned undersea vehicle support to NOAA marine research; to support diving activities; and to develop and provide the advanced technology necessary for manned underwater operations. (3) To develop and implement data acquisition capabilities to meet NOAA and national requirements for marine meteorological and oceanographic measurements through the development of ocean data buoys and other data acquisition systems.

To accomplish these objectives, the OOE has three major elements: the Ocean Instrumentation Engineering Office (OIEO), the Manned Undersea Science and Technology (MUS&T) Office, and the NOAA Data Buoy Office (NDBO).

Five areas have been identified as those needing to be addressed by advance technology to meet the needs of future ocean applications: (1) measurement, (2) ocean operation, (3) ocean structures and systems, (4) ocean energy, and (5) ocean technology exchange. Over the next five years this program will make a transition from being one of almost entirely technology development to a balance between technology development and application systems development. As building blocks become available through technology development, they will be incorporated into systems and demonstrated for application to major NOAA programs such as climate, offshore monitoring, fisheries, resource assessment and environmental services.

The program presently is in a technology assessment and planning mode. Workshops have been conducted in areas such as seafloor engineering, seafloor imagery, and ocean current measurement. Measurement instruments and standards are being assessed. Where deficiencies have been identified in each of these areas, initial steps have been taken toward improving them through development sponsorship.

At present, there are elements of seafloor engineering in all of the five areas enumerated above. Seafloor engineering research and development is conducted within the OOE in four different operational modes: (1) a limited amount of research is funded by the OOE and released to NOAA laboratories, (2) OOE funds support some research in industry and academic organizations, (3) non-NOAA governmental agency funds are administered by the OOE to support

research in other governmental laboratories or in industry, and (4) OOE cooperates with other governmental agencies and industry to share the funding of these cooperative projects.

### Outer Continental Shelf Environmental Assessment Program by William Jeffers

The Outer Continental Shelf Environmental Assessment Program (OCSEAP) of the NOAA Environmental Research Laboratory was initiated by the Bureau of Land Management (BLM) in 1974 to obtain background information for management decisions that may be necessary to protect the environment from damage during petroleum exploration and development. NOAA's OCSEAP office plans and directs the Alaskan program for BLM. Field studies are carried out in all nine lease areas, ranging from the Northeast Gulf of Alaska area to the Beaufort Sea area, with the distribution of effort conforming to BLM's proposed sale schedule.

The research program is designed to address six basic tasks: (A) determination of contaminant baselines prior to exploration; (B) estimation of potential sources and levels of contamination accompanying exploration and development; (C) identification and assessment of environmental hazards that may affect exploration and development; (D) determination of how pollutants might be transported if spills occur, and probable trajectories; (E) identification and characterization of biological receptors of pollutants; and (F) determination of potential effects on the biota and ecological systems from spills. Task C, Hazards, includes that portion of the research effort that is relevant to seafloor engineering needs.

Funding for this program is provided on an annual basis by BLM after approval of technical development plans prepared by the NOAA/OCSEAP office. This office in turn contracts out all research activities, provides guidance to investigators, monitors progress, and synthesizes results. The level of funding for Hazards is about \$2.4 million in Fiscal Year (FY) 78 and projected at about two million in FY 79.

Table 1 is a summary list of all potential hazards considered to be of concern in the Alaskan OCS areas. Not all of these are applicable to each lease area or to the subject of seafloor engineering.

The research effort relevant to seafloor engineering needs planned for accomplishment in FY 78 includes the following tasks: seismic and tectonic hazards, surface and nearsurface faulting, seafloor

Table 1. Hazards.

| | |
|---|---|
| Task C-1 | Determine seismic and tectonic hazards in, and peripheral to, regions proposed for petroleum development. |
| Task C-2 | Determine hazards to petroleum exploration and development resulting from surface and near surface faulting. |
| Task C-3 | Determine the types and extent of natural seafloor instability. |
| Task C-4 | Evaluate areas of seafloor erosion and deposition. |
| Task C-5 | Evaluate rates of change in coastal morphology, with particular emphasis on rates and patterns of man-induced changes. Locate areas where coastal morphology is likely to be changed by man's activities and evaluate the effect of these changes. |
| Task C-6 | Determine the extent and character of ice-bonded subsea permafrost along the Alaskan coast. |
| Task C-7 | Characterize the frequency of occurrence, geographical distribution, and nature of ice gouging phenomena. |
| Task C-8 | Determine, map, and interpret the distribution and pore pressures of shallow overpressured sediments. |
| Task C-9 | Determine the stress-strain relationships in various types of sea ice encountered along the Alaskan coast to permit calculation of ice forces and loads on structures. Determine the range of forces and extremes of stresses and forces that may be placed on platforms and facilities by ice. |
| Task C-10 | Synthesize existing literature to provide analysis of the frequency, intensity, and effects of extreme oceanic events. |

instability, erosion and deposition, subsea permafrost, and stratigraphic hazards. Information on the lease areas being studied and funding levels is available from this office.

Plans for the future are uncertain depending on the annual funding cycle from BLM. In FY 79 efforts in hazards will be slightly reduced and somewhat redirected, as shown in Table 2.

Table 2. Fiscal year 1979 future plans for hazards tasks.

1. Reduce level of reconnaisance seismic surveys and concentrate on delineating suspected active faults.
2. Concentrate on studies of unstable sediments that have been located; slumps, gas charged sediments, moving bed forms.
3. Expand seismology studies by adding seismograph and strong

motion instruments at selected sites to improve coverage. Install more OBS if prototype in Northeast Gulf of Alaska provides useful data in FY 78.

4. Continue measurements of geotechnical properties of sediments in areas of particular interest.

DEPARTMENT OF ENERGY by Donald Guier

The purpose of the Department of Energy (DOE) Oil, Gas, Shale and In Situ Technology (OGSIST) offshore technology program is to stiumlate and accelerate offshore oil and gas development. The OGSIST offshore technology role has not been defined, and therefore, the future extent of the program is unclear. However private sector capabilities will not be duplicated, established activities and capabilities of other Federal agencies will not be duplicated, the primary "user" of DOE developed technology is industry (other government agencies may also be users); and the planning and execution of programs and projects will ordinarily be in cooperation with industry and other government agencies. DOE authorities and policies provide considerable flexibility for collaboration; emphasis will be on short-term results; and national policy and priorities, reflected in <u>overall</u> DOE appropriations, provide the <u>potential</u> for substantial R&D support, provided opportunities meeting the above criteria can be identified.

Seafloor engineering as relates to outer continental shelf (OCS) oil and gas is an area prominently and consistently identified as appropriate for government support. The Marine Board of the National Academy of Engineering has formed a Committee on Offshore Energy Technology which will address these questions, among others: (1) R&D needs for offshore oil and gas development appropriate for Government involvement, including and especially knowledge of conditions in the offshore environment which affect structures, pipelines and operations; (2) which government agencies have authorities, capabilities and programs appropriate to the R&D needs identified; and (3) means of better government-industry cooperation in offshore energy technology.

This Marine Board report and program deliberations within DOE will help firm up the OGSIST role and program in seafloor engineering. We have been pursuing a few selected projects, including a significant initiative to develop an advanced seafloor instrumentation system jointly with the USGS and NOAA.

NATIONAL SCIENCE FOUNDATION by Charles C. Thiel and Charles Babendreier

Opportunities for seafloor engineering research exist within two parts of the National Science Foundation (NSF). Proposals emphasizing fundamental engineering research with and without direct applications should be directed to the Engineering Mechanics Section of the Engineering Division, consisting of the Structural, Materials and Geotechnical Engineering Program, the Fluid Mechanics Program, the Soil Mechanics Program, and the Water Resources, Urban and Environmental Engineering Program. Funding levels of the seafloor geotechnical proposals are commensurate with the needs of the proposed studies.

The Research Applied to National Needs (RANN) Program of the NSF was reorganized into the Applied Science and Research Applications (ASRA) Program in 1978. Seafloor engineering proposals may be considered by ASRA in two programs. If the proposal applies to engineering needs specifically and directly related to the Earthquake Hazards Mitigation Program, it will be considered by the Problem-Focused Research Applications Division. Other proposals which are applied research in nature will be considered by the Division of Applied Research in their Applied Physical, Mathematical, and Biological Sciences Program. ASRA does not have explicit programmatic activities focused on seafloor engineering.

U.S. GEOLOGICAL SURVEY by Paul G. Telecki and Dwight A. Sangrey

In 1974, as part of its marine geology program, the U.S. Geological Survey began geotechnical studies in the Mississippi Delta region. Rapid increase in offshore oil and gas discoveries in the area necessitated an understanding of the distribution of geologic hazards and the processes responsible for them. The Delta Project's objectives included several interrelated topics, namely: (1) detection of biogenic methane gas and its influence on the stability of sediments; (2) sediment mass movement, especially mudflows; (3) wave pressure-pore pressure interaction relative to the shear strength of marine soils; and (4) the geotechnical and acoustic properties of the three phase system of gas-water-sediment.

The study of pore pressure variations in soft sediment under loading by storm waves became the principal goal of SEASWAB (Shallow Experiment to Assess Storm Waves Affecting the Bottom). Institutions participating in this investigation were the Coastal Studies Institute of Louisiana State University, the Departments of Oceanography and Civil Engineering of Texas A&M University, the Marine Geotechnical Laboratory of Lehigh University, the Sandia Laboratories of the Department of Energy and the Atlantic

Oceanographic and Meteorological Laboratories of the National Oceanic and Atmospheric Administration. The test site was made available by the Shell Oil Company. The first field study was conducted in the fall of 1975, the second was completed in 1977. SEASWAB produced many unanticipated results and generated a continuing dialogue among Government, academic and industry scientists and engineers. SEASWAB type experiments are continuing and plans are to extend them to the continental slope offshore of the Delta and to the Gulf of Alaska.

While the Delta Project exemplifies basic research in seafloor engineering seeking solution to well-known shortcomings, the U.S. Geological Survey has also been routinely collecting, analyzing and interpreting environmental hazards data from the U.S. Continental Shelf. In response to the Department of Interior's responsibilities for orderly and safe development of the Nation's offshore mineral resources ("Outer Continental Shelf Lands Act" of 1953 and "Mineral Leasing Act" of 1920), the Bureau of Land Management administers the OCS environmental assessment program designed to establish, among other goals, the marine hazards present in prospective oil and gas lease areas. The U.S. Geological Survey uses matching funds to participate in this program. The Survey's ships are used on an almost year-round operational schedule to map surficial sediment distributions, study sediment transport, scour and bedform mechanics, collect and analyze cores from known locations of weak sediments, conduct geochemical analyses, map the distribution of faults. Corollary work on evaluating the probabilities of earthquake potential in OCS regions is based on the earthquake measuring network operated by the Survey. As part of these activities, the USGS has promoted and/or conducted instrument development designed to obtain specific types of geotechnical and oceanographic data on or near the seafloor. Examples in this category are the tripod-based current-sediment flux-wave pressure measuring sensor assemblies, and the Sandia-engineered seismicity-geotechnical instrument packages.

To supplement the public data resulting from the marine research activities, the USGS also acquires large quantities of proprietary industry data on offshore hazards on a site-specific basis and in greater detail. The combination of data sets are used to evaluate the hazard potential of offshore tracts prior to sale. In the post-sale period, the information serves to evaluate the environmental conditions, environmental loading and foundation characteristics of sites on which industry plans to install petroleum production platforms. This procedure is referred to as the Platform Verification program which will be implemented in 1978. It is the major regulatory process in the post-sale period, principally

involving fixed production platforms and as such it is pertinent to the subject of seafloor engineering. For clarification, the Platform Verification process is only one element of the regulatory aspects of post-sale activities in the OCS, all of which reside with the USGS.

The verification process is designed to meet the requirement to ensure safety of structures and safe operational conditions. Exploration is moving into deeper waters, more hostile environments and leasing is opening up regions where petroleum development experience is limited. Furthermore, as demonstrated by the North Sea experience, new development concepts will be introduced to cope with new engineering problems offshore. The range of environmental concerns that both industry and Government will encounter, while developing the mineral resources of the Continental Shelf, will be much more varied than those in the North Sea. Good examples of this are earthquake shaking potential in Alaska and Southern California and sea ice in Alaska.

To obtain a better understanding of the environmental conditions and expected environmental loads on offshore structures, the USGS has completed contracted studies in three OCS areas: the Gulf of Alaska, the Southern California Borderland and the Baltimore Canyon. These investigations are forerunners of a planned program on environmental hazards analyses and structural engineering evaluations in each OCS area in support of the verification process. The program is oriented toward assembling relevant information and conducting comprehensive analyses for developing design parameters for offshore platforms. The scope of activities in progress or planned include: (1) determing the nature, magnitude and extent of environmental hazards in OCS areas, (2) specifying extremes and probabilities of occurrence for natural hazards, (3) developing standardized methodology for geotechnical measurements and analyses, and (4) integrating hazards information of diverse topical origins for the purpose of generating the necessary input to the development of design parameters and the evaluation of structural responses.

With respect to seafloor engineering, the following critical topical elements have been included: (1) improvement in soil property measurements, (2) in situ and laboratory analyses and modeling of dynamic behavior of soils under wave and earthquake frequencies, (3) investigations of seafloor scour and the mechanics of sediment transport and bedform stability, (4) mapping, determination of the recency and the evaluation of reactivation potential of faults, (5) measurement of mass movement and the estimation of rates of movement, (6) geotechnical properties of gas-charged sediments (including clathrates), (7) mapping the distribution of surficial sediments

and their properties, (8) measuring and modeling seismic ground motion for deriving parameters on structural accelerations and foundation failure, (9) using oceanographic (wave, current) data as input to soil mechanics problems, and (10) investigating Arctic seafloor problems, such as offshore permafrost and ice scour in sediment.

The USGS is in the process of establishing an interactive information system for the internal management of data resulting from these investigations, together with data obtained through the regulatory process. The purpose of this system is to provide quick access to site-specific information relevant to the evaluation of design plans submitted by industry. It is the intent of the USGS to make the public portion of the information contained in the system available to those with legitimate needs for the information at a price bounded by the operating/reproducing costs. One should anticipate that at its inception most geotechnical data may be confidential in nature, a consequence of the long lead-time industry has had on developing an understanding for the offshore engineering problems.

One can naturally conclude that the Government's scientific and engineering capabilities must be on par with those of industry if the regulatory process is to function smoothly and cost-effectively. To this end, the USGS has added and continues to add personnel familiar with offshore practices to its rosters. In another area, the USGS and the Department of Energy have been exploring the means of conducting, and legal conditions governing, government/industry cooperative research projects. Two kinds of advantages could be accrued from joint involvements, one being the cost savings realizable from sharing research and development expenses, the other is in the commonality of the data base on which development decisions are made.

The Geological Survey's involvement in the offshore is not limited to petroleum development. The Survey has an historical record in basic and applied seafloor research. Its marine scientists have been involved in investigations with manned submersibles and habitats, in project FAMOUS and in many cruises of the Deep Sea Drilling Project. In 1976, the USGS conducted the Atlantic Margin Coring program using the Glomar Conception. Valuable seafloor engineering data were obtained and reported from this study along with the discovery of a major aquifer off the coast of New Jersey. Other offshore coring activities are planned for the 1980's. Other pending programs, such as the mining of shelf and deep ocean minerals, will benefit from the expertise accumulated in seafloor research over the past two decades.

In reference to the summary of seafloor engineering needs, stated in this document, the USGS prefers not to make the impression that those needs represent either the opinion or the programmatic needs of the Survey.

In conclusion, the USGS believes the subject of seafloor engineering is timely and necessary to the conduct of developing the Nation's mineral resources. The USGS intends to carry on with its programs in seafloor research in response to legislated responsibilities and in anticipation of problems it will have to solve in the future.

U.S.NAVY

Naval Facilities Engineering Command-
Civil Engineering Laboratory by Henry Gill

Introduction.--Although the NOAA assessment of seafloor engineering needs will not necessarily encompass all of the Department of Defense requirements in that area, the following information is provided to describe related technology that will result from the Navy's Ocean Facility Engineering Program. Approximately half of that program, assigned to the Civil Engineering Laboratory through the Naval Facilities Engineering Command, is performed on contract to private industry and academic institutions. Including technology such as trenching and trafficability, the funding level averages about a half million dollars per year. A brief summary of the program will be provided along with a discussion of general trends anticipated.

The overall objective is to develop the capability to site naval undersea facilities and predict their interaction with the seafloor. Those facilities may be located at any ocean depth from the surf-zone to 20,000 feet (6100 meters). They include facilities resting on or embedded in the bottom, floating surface facilities moored to the seafloor, and buoyant facilities suspended in the water column. Seafloor information is required also for constructing, implanting, inspecting, operating, maintaining, and repairing those facilities and the utilities required in their operation.

The Navy's program is altered in response to changing requirements of the operating forces. Those requirements are made known to the Naval Facilities Engineering Command, which assigns the responsibility for their solution to the Civil Engineering Laboratory. Many times technology developed by private industry or developed under sponsorship by the nonmilitary sector of the federal government is directly applicable. If Navy-sponsored R&D is needed to

meet the requirements, transfer of the technology to the private sector is maximized by arranging participation of private industry and other agencies to the extent practicable, and by disseminating results as widely as possible.

The technology in seafloor soil mechanics and foundation engineering is reaching a state of maturity that will allow most of the typical geotechnical engineering problems to either be accommodated in design, or avoided. For example, a major thrust recently has been research on the prediction of the behavior of direct embedment anchors in any seafloor sediment under long-term static, cyclic, and dynamic loadings. That work is nearing completion with the major remaining deficiency being the ability to provide reliable predictions of anchor holding capacity in rock; that deficiency is presently being addressed. However, as the following examples will show, a relatively large amount of work remains to be done in applying seafloor geotechnical information to nontypical Navy needs associated not only with supporting structures, but also with operating equipment on the ocean bottom.

Seafloor Soil Sampling and Testing.--Although much work has been done during the past two decades to obtain reliable cores of deep ocean sediments, the capability to obtain samples of good engineering quality to sediment depths of at least 30 feet is not adequate. Other problems are the difficulty in handling the long cores from typical Navy vessels and depth reference within the sediment. During recent coring operations the desirable features of piston coring systems used by various agencies throughout the world have been investigated, and in some cases, proof-tested. A corer concept consisting of the most optimum assemblage of those components from the standpoint of reliability, quality, and handleability, has been selected. Though each component has been tried, they have not been combined in the same system. Funds are being sought to allow the coring system to be assembled and tested.

It is not possible to avoid disturbance of these soil samples; therefore, it has been necessary to develop procedures to correct laboratory-measured engineering properties to compensate for this disturbance. Those correction techniques, based upon negative residual pore pressures on clays and triaxial testing for more permeable sediments, are nearing completion.

For cohesionless sediments, sampling is so unreliable that in-situ testing is necessary. Water depths to 1,000 feet (305 meters) are being considered. Candidate in-situ testing procedures are being evaluated in shallow-water ocean experiments using equipment such as heavily instrumented vibracorers and expendable penetrometers

(described later). When the most effective approach is identified, the testing system may be developed and tested.

Navy construction divers sometimes require light-duty, hand-held equipment to get a cursory measurement of soil properties to shallow sediment depths near shore. A family of experimental tools has been developed to take samples and to perform in-situ vane shear and standard penetration-type tests. Some additional improvements to those techniques may be done, but a major effort is not anticipated.

Expendable Penetrometer.--Because it takes about four hours to make a round trip with a corer in 15,000 feet (4600 meters) of water or more, and more time is required to perform tests on the samples received, an expedient means to measure sediment strength in-situ was needed. An expendable penetrometer was developed that can be dropped from a ship to make such a measurement in about four minutes in water depths as great as 20,000 feet (6100 meters). It consists of a lead-filled pipe about three inches (75 mm) in diameter and five feet (1.5 meters) long, with a constant frequency 12-kHz sound source attached. An analysis of the Doppler shift of the frequency of the sound signal received through the water column as the penetrometer slows down while embedding in the sediment provides an accurate determination of depth of penetration versus time and deceleration versus depth. From those measurements, sediment strength can be estimated with sufficient reliability for many Navy applications. At-sea testing of these penetrometers is now underway.

Acoustic Measurement of Geotechnical Properties.--There are conditions, such as the siting of rapidly deployable facilities for handling supplies for amphibious operations, where the expediency of acoustic surveys is necessary. These surveys are also valuable for preliminary siting and interpolation between mooring sites in the very deep ocean. The Navy is reviewing recent developments by oceanographers and geophysicists to determine the potential improvement possible in present geophysical exploration techniques as applied to engineering needs. A controlled experiment is being arranged at a site of known characteristics where discrepancies in data interpretation will be determined. If results are promising, follow-on work on both direct and oblique reflectivity and the hardware required for making the surveys will be conducted. It is expected that if these interests are pursued to completion, joint participation of other funding agencies will be necessary.

Natural Hazards.--The objective is to ensure that a capability exists to either design around natural hazards, such as earthquake effects, slope instability, scour, deposition, and turbidity currents, or to select sites where these hazards are not possible. This capability is essentially adequate for present Navy requirements, but scour is still of concern. A small effort to alleviate that concern is being considered, but it is expected that sufficient capability presently exists within private industry.

Holding Capacity of Direct Embedment Anchors.--The Navy is using lightweight anchors with long-term holding capacities of 100,000 pounds (45 megagrams) or more that are installed by firing a projectile into the seafloor. Since they will hold loads in any direction, including uplift, they are particularly beneficial in deeper water and in cases where the handling of heavy anchors is a problem. They are also very practical for use in coral or rock seafloors where conventional anchors do not hold properly. A program is nearing completion to provide reliable predictions of the long-term holding capacity of these anchors in sediments under any loading from static to cyclic or dynamic. Involved is the prediction of the depth of penetration of the projectile, the uplift distance required to key the fluke, creep under long-term static loading, and the degradation of holding capacity under nonstatic loading. The largest problem remaining is to determine the most effective projectile for use in hard rock bottoms and the trustworthy holding capacity of those projectiles. Testing and analytical work is underway.

Seafloor Work Systems.--Undersea work systems are presently being considered for use in the protection of cables and pipeline in the surfzone and in the burial of seafloor cables in the deep ocean. Although most nearshore problems are solved by rock bolting, there are cases where this technique is not cost effective or reliable. For those cases, a slot cut through rock or coral provides an effective solution. Bottom-resting cables in deeper water are frequently broken when snagged inadvertently, and burial to about three feet (one meter) in sediments to water depths of about 6,000 feet (1800 meters) prevents most of the breaks. Related R&D efforts underway include further development of cavitating water jets for trenching in rock, improvement of conventional rock trenching techniques, the effectiveness of lubricating skids in reducing drawbar pull, optimum running gear for soft soil mobility and negotiation of slopes and obstacles in the surfzone, energy efficiency and effectiveness of conventional water jetting for trenching in sediments, and the energy and drawbar pull reductions possible by using vibratory plowing in sediments. Component testing and analytical work is presently being conducted. If,

after the most desirable combination of components is selected, it is considered to be cost effective to continue the development of prototype cable burying equipment, full-scale cable burying systems will be assembled and tested.

Summary.--The above examples provide a summary of the seafloor-related research and development being conducted under the Ocean Facility Engineering Program of the Navy. Although the problems addressed are unique to the Navy, it is expected that mutual benefits will continue to be derived from close cooperation and occasional joint programs with agencies conducting seafloor engineering research and development for nonmilitary applications.

### Naval Research Laboratory by Paul Walsh

The Ocean Technology Division of the Naval Research Laboratory has for many years been doing research on the response of structures to dynamic loads. This is a broad program consisting of work in hydrodynamics, and the mechanics of materials; fracture; fatigue; corrosion; non-destructive testing; stress analysis; etc. as well as structure dynamics. But the work of interest here is that of offshore structures partially embedded in or resting on the sea-floor and loaded by surface waves and currents. In this case we are concerned with the response of the structure as a system taking into account the fluid-structure interaction and the soil-structures interaction. We wish to be able to model the soil as an engineering material.

Our objective is to predict the probability of failure of the structure as a function of time so we are particularly concerned with the need to predict the characteristics of the soil after it has been subjected to the loads imposed by the structure for long periods of time, (about 10-15 years), in a way that is analogous to predicting the rate of crack growth in steel.

## RECOMMENDED RESEARCH PLAN AND PRIORITIES

### BACKGROUND

A draft research plan (Appendix B) was prepared for distribution to practitioners in most of the identified fields of seafloor engineering in industry, academia, and government. Appendix C lists the names and addresses of the 145 persons to whom the draft plan was mailed. By this means, the preliminary plan was distributed to a large number of users for a critical review.

Table 3 shows the responses received by February 1, 1978, which was the cutoff date; five additional responses arrived too late to

be included. The numbers listed in this table are considered to represent an adequate response, partly because several individuals in industry usually replied on a single survey form. Furthermore, the governmental recipients were informed that they need not respond and a number of persons receiving information copies did not respond.

Table 3. Responses

| | Plans Distributed | Responses Received | Percent Responses |
|---|---|---|---|
| Industry | 71 | 15 | 21 |
| Academia | 32 | 12 | 37 |
| Government | 42 | 9 | 21 |
| Totals | 145 | 36 | 26 average |

Appendix B is essentially the plan that was distributed for review, with the addition of a few modifications made later. It contained a request for response to five questions. The information received in response to these questions was collated and grouped according to industrial, academic, or governmental affiliation. The industrial category was further divided into petroleum industry and all other industries to learn if there was a significant difference in responses. There was not.

A preliminary draft of Appendix B served as the major input document for a review meeting attended by the small group of invited specialists representing industry, academia, and government. Appendix D names the persons invited and those attending the review meeting held at the University of Texas in Austin on February 15-16, 1978. This meeting was organized with four principal objectives: (1) to hear brief presentations of ongoing seafloor engineering research and development and to learn of funding opportunities within the federal government, (2) to permit an opportunity for industrial and academic participants to interact with the governmental representatives on a one-to-one basis, (3) to recommend a research plan for governmental funding, and (4) to assign priorities to research areas contained in the research plan.

Appendix B contains two types of responses. The first type is a tabular listing of (1) the numbers of responses regarding the extent of proprietary information within the respondent's organization,

(2) the short- and long-term timeliness of specific subjects, and (3) the priority assigned to the question based on the general importance of the subject and also the relationship of the subject to specific engineering needs. The second type is a listing of comments written in response to a request for respondents to identify deficiencies and needs for (1) instrument development, (2) in situ measurements, (3) analytical procedures and predictive models, (4) extended field observations including monitoring, and (5) any other deficiencies and needs that were not specified. In Appendix B, following the comments given in answer to each of the five questions, some of the points considered to be important and relevant are briefly summarized.

Several respondents from industry and government wrote detailed letters instead of answering the draft plan sent to individuals within an organization. While these letters were not circulated at the review meeting, some of the information contained in them was brought out at the meeting and discussed by the participants.

Two major parts of the input document (a preliminary copy of Appendix B) were reorganized at the review meeting into three new categories: (1) soil properties and behavior, (2) geotechnical environmental hazards, and (3) soil-structure interaction problems for cooperative field investigations. In addition, data transfer systems were discussed at the meeting; this subject constitutes a fourth category that will be presented subsequently.

Within each of the three tables itemizing recommendations and priorities, priority 1 connotes an identified high priority engineering research need, priority 2 refers to an identified medium priority engineering research need, and priority 3 represents a desirable engineering research need. The numbered subjects within each priority classification are unranked. The listed priorities are relevant to the year 1978; in future years, it is likely that some of the designated priorities may increase or decrease in importance.

It was the consensus of the participants that they should not specifiy which federal agency or agencies should undertake any of the research areas recommended.

## SOIL PROPERTIES AND BEHAVIOR

Table 4 contains recommendations and priorities for the federal funding of research in the area of marine soil properties and behavior. The two priority three items are indicative of a number of problems that could be identified for relatively low-level research support; this category is not intended to be inclusive.

Table 4. Soil Properties and Behavior: Recommendations and Priorities

Priority 1 (High)

1. Shear strength (short- and long-term; undrained and drained); creep strength; cyclic strength; deformation characteristics; and bearing capacity
2. Strength changes, including liquefaction, and stress-strain behavior of soils under dynamic and repeated loading, particularly under long-term cyclic loading
3. Development of improved soil sampling techniques to minimize sample disturbance and development of improved procedures for the quantitative assessment of sample disturbance and its causes
4. Measurement offshore of both microseismic activity and strong motion activity in areas of concern
5. Pore pressure and state of stress, particularly in situ and in areas of concern

Priority 2 (Medium)

1. Measurement of free-field ground motion and correlation with concurrent, measured structural response
2. Stress-strain relationships, including state of stress
3. Compressibility characteristics
4. Time-consolidation and permeability
5. Quality, quantity, and state of gas present, particularly in situ
6. Fossil permafrost in seafloor soils
7. Statistical characterization of the geotechnical properties of specific seafloor soil types
8. Evaluation of geophysical and remote sensing techniques for site characterization: definition of soil types, their geometrical boundaries, and their geotechnical properties
9. Disturbance of granular soils under wave action, with particular relationship to outfalls and pipelines

Priority 3 (Desirable)

1. Classification and consistency, unit weight, and mineralogical composition
2. Composition of pore-water electrolyte (salt content and its effect on geotechnical properties)

The review meeting participants were in general agreement with the responses from the draft plan (Appendix B) regarding means, methodology, and procedures. They were in particularly strong agreement with the common response that measurements were more needed than the improvement of models. There is a deficiency of available data for use in calibrating existing, as well as future, soil models.

## GEOTECHNICAL ENVIRONMENTAL HAZARDS

Table 5 contains recommendations and priorities for the federal funding of research in the area of geotechnical hazards in the marine environment.

Table 5. Geotechnical Environmental Hazards: Recommendations and Priorities

Priority 1 (High)

1. Slope stability
   Detection of submarine landslides, slumps, scarps, and faults, including location, age, and size; site surveys for assessment of potential failure of sediments under conditions of earthquake and other stresses; determination of the probability of repeated movements and the rates of movement; and prediction of soil loading on structures at and just below the seafloor resulting from seafloor instability

2. Liquefaction
   Liquefaction potential and strength loss due to pore-pressure buildup under cyclic loads; effects on the degradation of shear properties; techniques for evaluating general and localized liquefaction, caused by waves or by seismic loading, and its effects on the capacity of footings and piles and the stability of pipelines

3. Faults and faulting
   Techniques for identifying and evaluating the magnitude of probable seafloor fault movement, frequencies, and total displacements resulting from earthquakes that should be anticipated; mechanisms and consequences of fault rupture; and evaluation of the probability of fault movement

Priority 2 (Medium)

Consideration of the causes and consequences of scour and fill, including sand waves, both on the open seafloor and in association with structures

Priority 3 (Desirable)

Evaluation of the depth, extent, and frequency of ice gouging of the seafloor

The review meeting participants generally concurred with the replies to questions about means, methodology, and procedures contained in Appendix B. They favored the development of better samplers--particularly pressurized corers, fast response-time piezometers, and a means of detecting soil movements. The participants also were looking forward to the time that case-history evaluations of the proprietary soil models developed by the petroleum industry can be made and subsequently published. The participants also agreed with the respondents to the draft plan that at present measurements are needed more than additional soil models.

There was considerable discussion about several items that did not appear in answers to questions given in the draft plan. The participants were particularly concerned that some effects of cyclic loading showing successive or progressive deformation may be related to differences of measurement or of technique. They favored the interlaboratory calibration of test methods as an initial step towards the standardization of testing. This course of action was considered to be especially relevant to measurements, instruments, and data reduction techniques that might be applied to any verification program.

## SOIL-STRUCTURE INTERACTION PROBLEMS

Table 6 contains recommendations and priorities for the federal funding of research in the area of soil-structure interaction problems. The review meeting participants proposed that while most of the problems could be cosponsored and funded by both industry and government, other problems might be undertaken by one or more companies or by one or more governmental agencies. While the problems cited were ranked high- or medium-priority by the review meeting participants, the list was not considered to be exhaustive. The participants also wished to emphasize that many of the soil-structure interaction problems listed in Table 6 would be particularly applicable for cooperative projects in high latitudes, where much marine geotechnical research needs to be performed.

Table 6. Soil-structure Interaction Problems: Recommendations and Priorities

<u>Priority 1</u> (High)

1. Investigation of the performance of laterally-loaded piles in soils, with emphasis on fine sands and silts (static, slow cyclic, and dynamic or seismic loadings)
2. Developing loading and response data to improve the design of mudslide-resistant structures
3. Critical evaluation leading to the solution of "rational" or pseudo effective stress vs. empirical correlation methods for the analysis and design of axially-loaded piles
4. Performance monitoring of seafloor foundations[1/]

<u>Priority 2</u> (Medium)

1. Large-displacement lateral-load performance of pile groups (static, slow cyclic, dynamic or seismic loadings)
2. Estimation of allowable lateral and axial pile support in calcareous sands, particularly those composed of crushable tests or shells
3. Determination of sediment trafficability, with emphasis on pipelines, mining, and cables
4. Behavior of gravity structures founded on different types of soils under wave loading and/or seismic excitation
5. High capacity (>100 kip or 4.5 Mg) deep-sea anchorages, including coral and rock [2/]

<u>Priority 3</u> (Desirable)

None identified

The review meeting participants had two comments to add to the responses on soil-structure interaction given in the draft plan (Appendix B). They favored developing methods for appraising the reliability of predictions and to predict the performance of structures by considering the related distributions of soil properties.

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[1/] This problem was believed to be mistakenly ranked "medium" at the review meeting.

[2/] This problem was ranked "high" at the review meeting. Subsequently, it was learned that a medium-priority would be more appropriate.

## DATA BANKS AND RETRIEVAL SYSTEMS

The need for a data transfer system was discussed at the review meeting. Table 7 lists responses to the question given in the preamble of part 3, Appendix B, which elicited opinions on the desirability of having an acquisition and distribution system for seafloor engineering data.

Table 7. Responses Regarding the Desirability of Having a Seafloor Engineering Data Bank and Retrieval System

| | Number of Responses Strongly Favorable | Number of Responses Weakly Favorable | Number of Responses Not Favorable |
|---|---|---|---|
| Industry | 7 | 5 | 1 |
| Academia | 7 | 1 | 2 |
| Government | 6 | 1 | 0 |
| Totals | 20 | 7 | 3 |

Although the total response from the mail solicitation to this question was favorable, the review meeting participants questioned the cost effectiveness of accumulating specific geotechnical data in centralized facilities. The participants were more in favor of publishing geologic information on near-surface soils, which could be used in a preliminary way to estimate the range of geotechnical parameters. Subsequent site-specific data would later be acquired by industry. It was suggested that the needs of users be determined before embarking on the accession and dissemination of geotechnical data in a centralized data center.

## ACKNOWLEDGEMENTS

We are appreciative of the efforts of a large number of persons who contributed to this endeavor in many ways; it is our regret that space does not permit individual acknowledgement. Within the NOAA Office of Ocean Engineering, Mr. Joseph Vadus and CDR Samuel Sigmund graciously provided immeasurable assistance. We thank Mr. John Kofoed and Dr. Richard Bennett of the NOAA Atlantic Oceanographic and Meteorological Laboratories for their help. The following individuals in other governmental agencies provided particularly useful interaction in one or more meetings: Mr. Donald Guier, Department of Energy; Drs. Dwight Sangrey and Paul Telecki, U.S. Geological Survey; and Dr. Richard Swim, U.S. Navy. Early in the development of this project meetings were held in Houston with representatives of the Gulf Universities Research Consortium and of a number of companies engaged in sea-floor engineering. A number of useful ideas were generated at these meetings, and we thank the participants for them.

A preliminary draft of the draft plan was kindly critiqued by Mr. William Gardner, Woodward-Clyde Consultants, and by Mr. John Focht, McClelland Engineers, Inc., who made a number of helpful suggestions. We particularly acknowledge our appreciation to the many persons who answered our draft plan, who provided thoughtful comments and suggestions, and who wrote letters elaborating their ideas. The exemplary performance of the participants in the review meeting by providing a highly constructive critique of our draft research plan made the task of preparing this report appreciably easier.

APPENDIX A

RESEARCH REPORTS AND DOCUMENTS, 1976-78

Research Reports and Documents Prepared by Committees

A Report on the Atlantic Offshore Users Workshop, 1977. Delaware Sea Grant College Program, Newark, 292 pp.

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APPENDIX B

ASSESSMENT OF NATIONAL SEAFLOOR ENGINEERING NEEDS DRAFT PLAN

Recipient: ______________________ 9 December 1977

Dated Material--Please Return by December 30, 1977, to:

Dr. Adrian F. Richards
Marine Geotechnical Laboratory, 17
Lehigh University
Bethlehem, PA 18015

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ASSESSMENT OF NATIONAL SEAFLOOR ENGINEERING NEEDS
(Input for a Review Meeting)

Prepared by

Professors Hudson Matlock and Adrian Richards

## INTRODUCTION

The National Research Council report on <u>Seafloor Engineering: National Needs and Research Requirements</u>, published by the National Academy of Sciences in 1976, recommended a core program of engineering research. A number of other committees and organizations in the past two years also have recommended seafloor research programs or objectives; a compilation is given in Appendix A. There is reasonably consistent agreement in these reports as to what research is required in the national interest. This document is intended to focus these efforts and to define more specifically the national needs and priorities in seafloor engineering research.

A seafloor engineering review meeting has been proposed to identify and assess specific user requirements for seafloor engineering, to translate these requirements into organizational program elements, to establish short- and long-term priorities, and to determine program elements most applicable for support. The questions being addressed by this document, which will be the principal input to the review meeting, are intended to have broad applicability within organizations. The user requirements have been designed to be useful to all organizations concerned with funding seafloor engineering research. Many of the user requirements will be applicable to a single organization. Others will be applicable to programs and activities of more than one organization. Still others may best be accommodated by the cooperation of two or more organizations.

This document is being sent to individuals in industry and academia with the following request for response:

1.a. Do you concur with the broad and/or specific topics comprising the user requirements considered representative of previously-proposed and present user requirements?

b. If not, please indicate in the spaces provided what you consider to be your most urgent technical needs or problems and delete any user requirements of little need or relevance. (Legislative needs or problems are not within the scope of this study.)

2. How much of your organization's documentation is proprietary but available to the profession upon request and how much is too proprietary to be made available at present? Our concern is not to reinvent the wheel at the taxpayer's expense.

3. What is your opinion of the timeliness of the user requirements, expressed as short-term being less than five years ($<1983$) and long-term being greater than five years ($>1983$)?

4. Please indicate the priorities that organizations should place in funding either general or specific user requirements. The general needs are intended to cover the broad needs of the profession, while the specific needs are applicable to the requirements of your organization to solve specific engineering problems.

5. What are your ideas regarding the specific technical means, methods, and procedures that should be supported by public funds? Spaces are provided for suggestions.

Information copies of this document also are being sent to persons representing organizations known to be concerned with funding seafloor engineering research, who are invited to respond if they wish to do so.

After this document has been reviewed by mail, the comments, suggestions, priorities etc. made by you and your colleagues will be compiled, appropriate modifications will be made, and then the revised user requirements will be reviewed at a meeting of a very small group of experts selected from industry, academia, and government. When this has been done, then the organizations involved will have a common document defining user-orientated priorities that will be incorporated into the planning of funding programs.

Seafloor engineering has been defined for the purposes of this study to include only that part of marine geotechnics that is directly concerned with the seafloor. Environmental loads and driving forces, such as waves, ice, etc., will be included in other programs being developed; they will not be considered at this review meeting. Furthermore, while no water-depth limit has been applied, it is likely that major emphasis will be on the U.S. continental margins.

The research elements in this document are organized into three distinct parts: Part One is concerned with the seafloor in its natural state before structures are emplaced and other engineering activities affect it. Part Two is concerned with the seafloor after man's activities have affected it; principal emphasis will be on soil-structure interaction, in the broadest sense of the words. While it is recognized that some of these problems may need to be entirely or almost entirely industrial or performed by other organizations, there should remain close collaboration between industry and other organizations whenever possible. Part Three concerns the presumed national needs for the development and maintenance of data banks and information retrieval systems.

In the list of user requirements, no special reference has been made to specific seafloor engineering needs, such as for cables, pipelines, and deepsea mining. It is believed that the existing statements are sufficiently broad to cover these and other specialized needs of industry.

PART ONE: Natural, or Environmental, Seafloor Information Needed for Engineering Purposes*

Preamble:

Three programs are proposed; however, while the second and third could be considered part of the first, because slope stability and the dynamic or seismic properties of soils are of such great importance they have been separately listed. It is emphasized that Part One research must be relevant and pertinent to the present or future requirements of engineering work in the oceans rather than solely for purposes of scientific curiosity. Part One research should emphasize soils from the general regions in which future offshore construction is being planned, or on soils from other areas for the temporary purpose of modeling, testing, evaluating, etc.

| I. Soil Properties and State of Stress<br>A. For basic and mixed soil types (silica and carbonate sands; terriginous or pelagic clays; calcareous and siliceous biogenic oozes) both saturated and partly saturated or gassy | | Proprietary Documentation:[1] Your Organization<br>% Available Responses[2] | %Unavailable Responses[2] | Check Timeliness: Your Organization<br>Short Term: <5 yr Responses | Long Term: >5 yr Responses | Indicate Priorities[1] (1=High 2=Intermed. 3=Low)<br>General Importance of Subject Responses[3] | | | Relationship to Specific Eng. Needs Responses[3] | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | INP[4] | 3-100, 4<20 | 1-0, 5>80 | 8 | 2 | 1 | 5 | 4 | 3 | 3 | 4 |
| | IP | 1-75, 1<10 | 1-25 | 3 | 2 | 1 | 2 | 1 | 1 | 1 | 3 |
| 1. Classification and consistency, unit weight, and mineralogical composition | A | 7>80, 1-0 | 1-0, 1-20 | 6 | 3 | 3 | 4 | 2 | 2 | 4 | 1 |
| | G | 6>90 | 1-10 | 6 | 3 | 6 | 2 | 0 | 4 | 2 | 0 |
| | Totals | 17>75, 6<20 | 5>80, 5<25 | 23 | 10 | 11 | 13 | 7 | 10 | 10 | 8 |
| | Ranking[5] | | | 3 | 5 | | 8 | | | 8 | |
| | INP[4] | 2-50, 3>75, 2<10 | 2-50, 3>90 1-25 | 8 | 2 | 8 | 2 | 0 | 9 | 1 | 0 |
| 2. Shear strength (short- and long-term; undrained and drained); creep strength; cyclic strength; deformation characteristics; and bearing capacity | IP | 1-75, 1<10 | 1-25 | 5 | 0 | 3 | 1 | 0 | 4 | 1 | 0 |
| | A | 6>90, 2<20 | 1-80, 2<10 | 7 | 3 | 11 | 0 | 0 | 10 | 0 | 0 |
| | G | 4-100, 1-75 | 1-25 | 6 | 1 | 8 | 1 | 0 | 6 | 1 | 0 |
| | Totals | 14>75, 5<20 | 5<25, 4>80 | 26 | 6 | 30 | 4 | 0 | 29 | 3 | 0 |
| | Ranking[5] | | | 1 | 7 | | 1 | | | 1 | |

[1] Please see Appendix 3 page 2, items 2 and 4, for a further description; information in parentheses appeared in original document.

[2] Number of responses-percentage available (or unavailable); some responses have been generalized.

[3] The number of responses in the three catagories (high, intermediate, and low) are listed from left to right.

[4] INP=industry, not petroleum; IP=industry, petroleum; A=academia; and G=government.

[5] The ranking designation is based solely on the total number of high priority or "1" responses. Should there be two or more identical totals, these are accorded equal ranking; e.g. for classification the ranking is 3rd in 10 and 5th in 10 under timeliness and 8th in 10 under both general importance and relationship to specific engineering needs.

| | | Proprietary Documentation:[1] Your Organization %Available Responses[2] | Proprietary Documentation:[1] Your Organization %Unavailable Responses[2] | Check Timeliness: Your Organization Short Term: <5 yr Responses | Check Timeliness: Your Organization Long Term: >5 yr Responses | Indicate Priorities[1] 1=High 2=Intermed. 3=Low General Importance of Subject Responses[3] | | | Relationship to Specific Eng. Needs Responses[3] | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 3. Compressibility characteristics | INP[4] | 1-100, 1-75 1-50, 3<10 | 1-50, 4>90 1-15 | 5 | 5 | 5 | 3 | 2 | 5 | 2 | 3 |
| | IP | 1-75, 1<10 | | 5 | 0 | 0 | 4 | 0 | 2 | 3 | 0 |
| | A | 5>90, 2<20 | 1-80, 2<10 | 6 | 4 | 6 | 3 | 1 | 5 | 3 | 1 |
| | G | 4-100, 1-60 | 1-40 | 4 | 1 | 5 | 3 | 1 | 4 | 2 | 1 |
| | Totals | 6<20, 11>75 | 3<25, 5>80 | 20 | 10 | 16 | 13 | 4 | 16 | 10 | 5 |
| | Ranking[5] | | | 6 | 5 | | 6 | | | 6 | |
| 4. Time-consolidation and permeability | INP[4] | 1-100, 3<10 2-50 | 2-50, 4>90 | 3 | 7 | 4 | 1 | 5 | 4 | 2 | 4 |
| | IP | 1<10 | | 4 | 1 | 1 | 2 | 1 | 2 | 2 | 1 |
| | A | 2<20, 5>90 | 1-80, 2<10 | 6 | 3 | 4 | 5 | 1 | 3 | 6 | 0 |
| | G | 4-100, 1-50 | 1-50 | 3 | 3 | 3 | 5 | 1 | 2 | 4 | 1 |
| | Totals | 10>90, 6<10 | 2<10 5>80 | 16 | 14 | 12 | 13 | 8 | 11 | 14 | 6 |
| | Ranking[5] | | | 8 | 2 | | 7 | | | 7 | |
| 5. Stress-strain relationships, including state of stress | INP[4] | 2>15, 2<10 | 1-25 4>90 | 5 | 5 | 5 | 4 | 0 | 6 | 0 | 3 |
| | IP | 1-75, 1-10 | 1-25 | 4 | 1 | 3 | 2 | 0 | 3 | 2 | 0 |
| | A | 1-50, 4>80 1-0 | 1-100, 1-50 1-20, | 8 | 3 | 8 | 3 | 0 | 8 | 3 | 0 |
| | G | 4-100, 1-75 | 1-25, 2-0 | 4 | 2 | 5 | 3 | 0 | 4 | 2 | 0 |
| | Totals | 11>75, 4<10 | 6<25, 5>90 | 21 | 11 | 21 | 12 | 0 | 21 | 7 | 3 |
| | Ranking[5] | | | 5 | 4 | | 4 | | | 4 | |

| | | Proprietary Documentation:[1] Your Organization %Available Responses[2] | Proprietary Documentation:[1] Your Organization %Unavailable Responses[2] | Check Timeliness: Your Organization Short Term: <5 yr Responses | Check Timeliness: Your Organization Long Term: >5 yr Responses | Indicate Priorities[1] 1=High 2=Intermed. 3=Low General Importance of Subject Responses[3] | | | Relationship to Specific Eng. Needs Responses[3] | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | INP[4] | 1-100, 3<5 | 5>95 | 5 | 4 | 2 | 7 | 1 | 3 | 3 | 3 |
| | IP | 1<10 | | 5 | 0 | 3 | 1 | 0 | 5 | 0 | 0 |
| 6. In situ pore pressure and state of stress | A | 3-100, 1-0 | 1-0 | 5 | 4 | 5 | 2 | 2 | 5 | 2 | 2 |
| | G | 2-100, 1-40 1-0 | 1-60, 1-0 | 4 | 2 | 9 | 0 | 0 | 5 | 2 | 0 |
| | Totals | 6-100, 6<5 | 2-0 5>95 | 19 | 10 | 19 | 10 | 3 | 18 | 7 | 5 |
| | Ranking[5] | | | 7 | 5 | | 5 | | | 5 | |
| | INP[4] | 1-100, 3<5 | 1-50, 2>95 | 4 | 4 | 1 | 5 | 4 | 2 | 2 | 6 |
| | IP | 1<10 | | 2 | 3 | 0 | 4 | 0 | 1 | 4 | 0 |
| 7. Quality, quantity, and state of gas present, particularly in situ | A | 3-100, 1-0 | 1-0 | 3 | 4 | 4 | 2 | 2 | 1 | 5 | 2 |
| | G | 2-100, 1-0 | 1-0 | 2 | 2 | 3 | 5 | 0 | 2 | 3 | 0 |
| | Totals | 6-100, 6<40 | 2-0, 2>95 | 11 | 13 | 8 | 16 | 6 | 6 | 14 | 8 |
| | Ranking[5] | | | 9 | 3 | | 9 | | | 9 | |
| | INP[4] | 1-100, 3<5 | 2>95 | 3 | 5 | 0 | 3 | 6 | 0 | 2 | 8 |
| 8. Composition of pore-water electrolyte (salt content and its effect on geotechnical properties) | IP | 1<10 | | 0 | 5 | 0 | 2 | 2 | 0 | 0 | 5 |
| | A | 3-100, 1-0 | 1-0 | 2 | 3 | 1 | 5 | 3 | 0 | 5 | 3 |
| | G | 2-100, 1-0 | 1-0 | 1 | 4 | 1 | 2 | 5 | 0 | 1 | 5 |
| | Totals | 6-100, 6<10 | 2-0 2>95 | 6 | 17 | 2 | 12 | 16 | 0 | 8 | 21 |
| | Ranking[5] | | | 10 | 1 | | 10 | | | 10 | |

| | | Proprietary Documentation:[1] Your Organization %Available Responses[2] | Proprietary Documentation:[1] Your Organization %Unavailable Responses[2] | Check Timeliness: Your Organization Short Term: <5 yr Responses | Check Timeliness: Your Organization Long Term: >5 yr Responses | Indicate Priorities[1] 1=High 2=Intermed. 3=Low General Importance of Subject Responses[3] | | | Relationship to Specific Eng. Needs Responses[3] | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 9. Liquefaction potential and strength loss due to pore-pressure buildup under cyclic loads; effects on the degradation of shear properties | INP[4] | 3>75, 4<10 | 2<25, 3>90 | 4 | 5 | 6 | 3 | 0 | 6 | 2 | 1 |
| | IP | 1<30 | 1-100 | 4 | 1 | 4 | 0 | 0 | 4 | 0 | 1 |
| | A | 6-100, 1-0 | | 9 | 1 | 9 | 1 | 0 | 10 | 0 | 0 |
| | G | 3-100, 1-50 | 1-50, 2-0 | 5 | 1 | 9 | 0 | 0 | 6 | 1 | 0 |
| | Totals | 9-100, 6<10 | 4<25, 4>90 | 22 | 8 | 28 | 4 | 0 | 26 | 3 | 2 |
| | Ranking[5] | | | 4 | 6 | | 2 | | | 3 | |
| 10. Effects of sample disturbance | INP[4] | 3-100, 4<20 | 2-100, 1-80 1-0 | 7 | 2 | 8 | 2 | 0 | 9 | 0 | 0 |
| | IP | 1<30 | | 4 | 1 | 4 | 1 | 0 | 4 | 1 | 0 |
| | A | 4-100, 1-0 | 1-0 | 8 | 2 | 8 | 2 | 0 | 8 | 2 | 0 |
| | G | 4-100, 1-40 | 1-60, 1-0 | 5 | 1 | 8 | 1 | 0 | 7 | 1 | 0 |
| | Totals | 11-100, 5<20 | 3-0, 3>80 | 24 | 6 | 28 | 6 | 0 | 28 | 4 | 0 |
| | Ranking[5] | | | 2 | 7 | | 3 | | | 2 | |

PART ONE: Natural, or Environmental, Seafloor Information Needed for Engineering Purposes*

I. Soil Properties and State of Stress

B. Means, methodology, and procedures needed for solution of user requirements

1. QUESTION: Instrument development (deficiencies and needs?)

ANSWERS

Industry: non-petroleum replies

- Better soil samplers (less disturbance).
- Development of new sampling equipment or improvement of existing sampling technique to provide high quality (as nearly undisturbed as possible) samples for subsequent laboratory testing to better understand the behavior of marine soils. Currently available sampling equipment and techniques provide badly disturbed samples which are only good for index properties testing and testing for remolded soils.
- Better samplers to prevent or reduce disturbance.
- Inexpensive methods of retriving high quality samples; inexpensive methods of measuring desired properties in situ.
- Simulation of the true boundary conditions of soil medium should be considered in the development of laboratory testing apparatus.
- Need free-fall strength measuring system for rapid surveys (high priority).
- Sand sampling (intermediate priority; experience available).
- In situ instrumentation (high priority; experience available).
- Prototype fdn. perf. instrumentation (high priority; experience available).
- Need capability to sense sediment shear strength, compressibility, and trafficability over large areas of deep ocean floor ($\approx$ 16,000 ft) at high speed and low cost.

Industry: petroleum replies

- Develop a real time pore pressure transducer.
- In situ measurement devices; laboratory devices capable of applying various stress paths.
- Presently being adequately covered in other research projects--some proprietary.
- (1) true triaxial testing devices, (2) penetrometer with pore pressure measurement capability, and (3) pressuremeter.

* Environmental loads and driving forces are not included in this study. The dashed line in front of a comment to a question denotes one reply.

Academic replies

- Reliable instruments (transducers, recorders, etc.) for use during storms.
- Better means of obtaining undisturbed samples, especially in large depths of water. Cone penetration device of Dutch type that also measures pore pressures during penetration. Perhaps improved field vane device?
- Need better low- and high-pressure piezometers; better equipment for long-term movement of sediments; refinements in data acquisition; storage and processing under field conditions.
- Hardware and techniques for obtaining relatively undisturbed samples need development.

Government replies

- Use of cones with pore-pressure devices; in-hole pressuremeters to get $\bar{\sigma}_3$ in situ.
- Pore pressure measurements; precise position monitoring instruments for studying rates of movement of seafloor. OBS - microseismic rather than strong motion.
- Sample disturbance and depth of sample.
- Greater emphasis must be placed on in situ instrumentation; i.e., piezometer and improved free-fall penetrometers.
- Corer, deployable from typical oceanographic vessels, that obtains high quality samples of all sediments to about 10 m (urgency=1, priority=1).
- Measurement of pore pressures under dynamic loading conditions.
- Major emphasis should be placed on in situ measurements through development and improvement of additional new and existing instruments.

Brief summary

Instrument development should emphasize sampling devices and reliable piezometers, penetrometers, and pressuremeters for in situ measurements.

I. Soil Properties and State of Stress

B. Means, methodology, and procedures needed for solution of user requirements

2. QUESTION: In situ measurements (deficiencies and needs?)

ANSWERS

Industry: non-petroleum replies

- State of stress gas content.
- Better data are needed on the relationship between laboratory and in situ data. There are discrepancies in the data we have seen.
- In situ measurements of soil behavior under static and/or dynamic loading condition have always been difficult and insufficient for engineer's needs. Innovated methods and equipment for a direct or indirect in-situ measurements of (1) in-situ stress state, (2) stress-strain behavior, (3) strength properties, (4) magnitude of pore pressure, and (5) soil properties (deformation and strength) degradation under static or dynamic loading are urgently needed.
- Seismic sounding technique should be better implemented and utilized for routine soil explorations.
- Are they really any better than cores for all measurements except pore pressure and gas present? (high priority--If in situ measurements are not required then much more work can be accomplished in a given period of time at much lower costs.).
- Strength (intermediate priority, experience available).
- Voil ratio (high priority).
- Stress-strain (intermediate priority).
- Shear strength, compressibility, and trafficability in nodule areas.

Industry: petroelum replies

- Stress-strain-strength measurement and stress state at rest measurements (including pore pressure, gas pressure and effective stress).
- Methods to predict in situ state of stress are required.
- We need instrumentation for the measurement of fundamental properties in place; current instruments measure only relative properties that cannot be related to fundamentals such as shear strength, compressive strength, and compressibility.
- Reliable means of in-situ pore pressure and undrained shear strength measurement should be a high priority with emphasis placed on interpretation of results; i.e., strain rate and vane size effects should be evaluated alongside the evaluation of disturbance and gas effects in laboratory tests to provide a "best estimate" in-situ strength profile for use in analyses.
- Penetrometer with pore-pressure measurement capability.
- Pressuremeter.

Academic replies

- More and better methods; environmental changes from seafloor to laboratory proportedly too severe to correct with better sampling procedures.
- More in situ studies needed, but only after laboratory analyses have shown that equipment, methodologies, and results will be meaningful.
- Pore pressure, turbidity (particle resuspension).
- Cone penetration and field vane data at sites where we also have a good knowledge of the net overburden stress and maximum past pressure to develop better correlations.
- Pore pressure measurements of both gas and water are urgently needed; in situ strengths of soft sediments are needed. Not enough locations have been studied for either of these measurements.
- Need for better in situ measurements of strength and stress-strain properties.
- Hardware and techniques need improvement relative to: (1) control of the boundary conditions in situ, (2) knowledge of boundary conditions in situ, and (3) minimization of "disturbance" during testing.

Government replies

- Need to get permeabilities; $\sigma$-$\varepsilon$ properties and damping in situ is very tough; need to get good quality undisturbed samples.
- In situ pore pressure, state of stress ($K_o$), gas content and phase, and density (unit weight).
- Still unclear how to relate the various in situ measurements to construction requirements.
- Capability to detect, delineate, and roughly measure engineering properties of soft layer under sand layers (10-30' thick) rapidly (urgency=1, priority=1). Is it possible to do this acoustically?
- Capability to rapidly classify sediments over an area or along a route (urgency=1, priority=1).
- Utilize in situ probe (unit weight, water content, and relative density) developed at University of California, Davis, by Professor K. Arulanandan.
- Needed: (1) vane shear apparatus, (2) densitometers, (3) piezometers, and (4) data acquisition systems.

Brief summary

The in situ measurement of the state of stress and/or stress-strain, pore pressures, and shear strength is particularly needed.

I. Soil Properties and State of Stress

B. Means, methodology, and procedures needed for solution of user requirements

3. QUESTION: Analytical procedures and predictive models (deficiencies and needs?)

ANSWERS

Industry: non-petroleum replies

- Constitutive model for bearing capacity and settlement in carbonate/calcareous sediments.
- Fair agreement, but too dependent on assumptions.
- Realistic stress-strain relationship should be developed for marine soils through laboratory testing and rheological models. Stress-strain relationship should be stress path, strain history dependent, and should be able to account for soil-water interaction. Analytical procedures of a realistic effective stress-analysis should be developed.
- Too many measurements are being made on cores which have lost pore water! This must be corrected (high priority)!!
- Three dimensional, effective stress-strain constitutive model for soils.
- Calibration of existing models with performance data.
- Predictive models for trafficability of deep ocean sediments.

Industry: petroleum replies

- Constitutive relation of soils.
- OK based on state of knowledge of properties of materials (<25% of analytical methods are proprietary; of the 25% proprietary, almost all of the methods are published).
- The need for new analytical procedures and new predictive models is of low priority. Our current analytical procedures and our current predictive models are far more powerful than the data going into them. We have powerful analysis tools but no work data to analyze.
- Improved methodology for liquefaction potential evaluation.
- Analytical model of interaction between penetrometer and surrounding soil.

Academic replies

- Enough procedures are available; however, we lack soil properties.
- Not much is needed for analytical procedures and predictive models concerning soil properties and state of stress. At present measurements are needed.
- Need for improved constitutive models for soil. Need for improved procedures for accounting for effects of sample disturbance.

Government replies

- This area is way ahead of our soil property input--I would not stress this work area.
- Dynamic loading (both earthquake and wave) of seafloor soils-particularly slopes. Pore pressure changes and dissipation during and after mass movement of sediments. Effects of gas in sediments on engineering behavior.
- Predictor models for penetrability and breakout.
- We still are interested in predicting anchor performance; however, such models might be site specific and would definitely be project specific. As projects come and go, our anchor loads and angles change a great deal.
- Holding-capacity predictive-procedures for conventional drag or deadweight anchors (urgency=1, priority=2).
- Examine effect of soil sensitivity on holding capacity of embedment anchors (urgency=1, priority=2, not proprietary).
- Improved constitutive properties of seafloor soils under dynamic loading for input to predictive models.
- Considerable geotechnical field data are required related to soil properties of basic and mixed types as well as saturated and partially saturated soils and the response of these various soil types to static and dynamic loads to improve and utilize existing predictive models of seabed stability and associated soil properties.

Brief summary

With respect to analytical procedures and predictive models, many responses indicated that measurements are in greater need than the development of models because there is a deficiency of analytical data in modeling. A few replies favored the development of constitutive and predictive models.

I. Soil Properties and State of Stress

B. Means, methodology, and procedures needed for solution of user requirements

4. QUESTION: Extended field observations, including monitoring (deficiencies and needs?)

ANSWERS

Industry: non-petroleum replies
- Undersea slides to infer existing properties and pore pressures in soil versus waves.
- Need full-scale real-life information.
- Case history studies of offshore structure and foundation performance are urgently needed to better understand the degree of conservatism or uncertainty in current methods of design.
- A general need for prototype foundation and soil behavior measurements; analytics and soil mechanics have far outstripped our ability to properly direct such technology and implement into current design practice.

Industry: petroleum replies
- State of stress in situ; seafloor and depth movements due to waves; seismic measurements (micro- and strong-motion); no data in area.
- We need a method for cheap, long-term pile load tests.

Academic replies
- Always required. More non-proprietary case studies needed. Much more emphasis on in situ-long term tests (settlement, creep, pore-pressure dissipation).
- See above. There is a definite use for extended field observations.

Government replies

- Anything you can do will be excellent. We badly need good case history documentation for almost all problems.
- In situ pore-pressure state in all types of marine sediments and environments. Rates of movement of seafloor sediments. Navy interests would not be at traditional offshore industry sites. They would be very site specific and probably difficult to fund.
- Long-term holding capacity of an embedment anchor (urgency=1, priority=1).
- Monitoring of erosion and sediment transport in the vicinity of structures on the seafloor.
- Long and short term field observations are required and can be made possible through the development of in situ instrumentation and improved sediment core sampling techniques.

Brief summary

Case studies, long-term monitoring, and state of stress in soils related to wave and seismic loads were the extended field observations most often cited.

I. Soil Properties and State of Stress

C. QUESTION: Other (What are your most urgent short- and long-term needs, if not given above?)

ANSWERS

Industry; non-petroleum replies

- Long Term: (1) Development of new methods or improvement of existing methods to increase the marine soil stability under static and dynamic loading and (2) development of better analytical and laboratory techniques to better understand the behavior of marine soil under loading condition imposed by marine environment and offshore structure.
  Short Term: (1) A data collection center for gathering and exchange of available information and (2) a critical review of existing laboratory and field testing methods for marine soil mechanics application.
- A quantitative measurement of the property of "stickiness" over the short term.
- Field measurements of prototype foundation element performance.
- Development (parallel to above) of competent in situ measurement instrumentation.
- Our most urgent needs were covered previously.

Industry: petroleum replies

- Test to destruction structures that are about to be abandoned.
- Very often specific soil data are best gathered at a specific site in connection with a specific project, and careful distinction should be made between data for regional investigations and data for site-specific or problem-specific studies. We believe that the general regional data proposed in Part One is of value in making very preliminary assessments of seafloor conditions and in no way should be designed to be a substitute for more detailed site specific studies. Item I-1 type information could be obtained relatively economically from disturbed samples; however, more expensive undisturbed samples will be required for the remaining items. Therefore, we believe the sites for obtaining the undisturbed samples should be very limited in number and carefully selected to represent regional trends.

Academic replies

- No university can generate the quality of data obtained by the oil companies because of the limited equipment funds available to universities.
- Need to define how much clay or what plasticity of soil etc. will prevent it from liquefying; i.e., how can you tell if a silty soil will liquefy or just deform?
- Effects of sample disturbance should be understood so that property measurements and behavior may be adjusted appropriately until such time as better coring equipment is available.
- Money!

Government replies

- See B2.
- Urgent needs are easy to justify expenditures for, and we are willing to pay to obtain the answers as they arise. Our schedules would not allow sufficient time for an urgent need to be included in a national plan. The federal budget cycles are such that a major Navy construction project is seldom in the system for more than 5 to 10 years.
- Penetrability of the bottom, i.e. sediment characteristics (strength, unit weight etc.), coupled with characteristics (geometry, weight, terminal velocity) of "penetrating objects" which affect penetrability.
- Sediment characteristics which affect breakout of objects embedded in the bottom.
- Soil characteristics which affect trafficability of the seafloor.
- What about the effect of temperature and temperature history on soil properties, especially since increased interest is developing in high latitude regions?
- What about investigations into soil micro fabric?
- Prediction of scour potential about seafloor foundations (urgency=1, priority=1).
- Measurement of geotechnical properties in the Arctic Ocean (urgency=1, priority=1).
- Prediction of ice scour (gouging) depth in the Arctic (urgency=1, priority=1).
- Identification of offshore ice-bound permafrost, its distribution, and annual changes in depth and thickness (urgency=1, priority=1).

Brief summary

Responses under this category were varied, and no summary is attempted.

| II. Slope Stability | | Proprietary Documentation:[1] Your Organization %Available Responses[2] | %Unavailable Responses[2] | Check Timeliness: Your Organization Short Term: <5 yr Responses | Long Term: >5 yr Responses | Indicate Priorities[1] 1=High 2=Intermed. 3=Low General Importance of Subject Responses[3] | | | Relationship to Specific Eng. Needs Responses[3] | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | INP[4] | 2>75, 4<20 | 2-100, 1-80 1-25 | 6 | 4 | 6 | 3 | 1 | 6 | 1 | 3 |
| | IP | 1<50 | | 4 | 1 | 3 | 1 | 0 | 4 | 1 | 0 |
| A. Properties of materials, and state of stress, particularly in situ | A | 5>90 | 2<10 | 7 | 2 | 7 | 2 | 0 | 6 | 2 | 0 |
| | G | 2-100, 1-60 1-0 | 1-40, 1-0 | 4 | 2 | 7 | 2 | 0 | 4 | 3 | 0 |
| | Totals | 9>75 5<20 | 4<25, 3>80 | 21 | 9 | 23 | 8 | 1 | 20 | 7 | 3 |
| | Ranking[5] | | | 1 | 6 | | 1 | | | 1 | |
| | INP[4] | 1-20, 4-0 | 3-100, 1-80 | 5 | 4 | 3 | 4 | 1 | 5 | 2 | 2 |
| B. Evidence of earlier slope instability from surface topography, stratigraphy, shear strength anomalies, etc. | IP | 2<50 | 1-50 | 2 | 3 | 1 | 2 | 1 | 2 | 3 | 0 |
| | A | 2-100, 1-50 1-0 | 1-50, 1-0 | 5 | 4 | 5 | 4 | 1 | 6 | 2 | 0 |
| | G | 2-100, 1-70 1-0 | 1-30, 1-0 | 3 | 5 | 5 | 3 | 1 | 3 | 3 | 1 |
| | Totals | 4-100, 8<20 | 2-0, 4>80 | 15 | 16 | 14 | 13 | 4 | 16 | 10 | 3 |
| | Ranking[5] | | | 2 | 2 | | 4 | | | 2 | |

| | | Proprietary Documentation:[1] Your Organization %Available Responses[2] | Proprietary Documentation:[1] Your Organization %Unavailable Responses[2] | Check Timeliness: Your Organization Short Term: <5 yr Responses | Check Timeliness: Your Organization Long Term: >5 yr Responses | Indicate Priorities 1=High 2=Intermed. 3=Low General Importance of Subject Responses[3] 1 | 2 | 3 | Relationship to Specific Eng. Needs Responses[3] 1 | 2 | 3 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| C. Measurements of in situ movements and rates of movements | INP[4] | 5-0 | 3-100, 1-0 | 2 | 7 | 3 | 2 | 2 | 3 | 2 | 3 |
| | IP | 1-0 | 1-0 | 4 | 1 | 4 | 0 | 0 | 3 | 2 | 0 |
| | A | 3-100, 1-0 | 1-0 | 4 | 5 | 6 | 3 | 1 | 5 | 3 | 0 |
| | G | 2-100, 1-40 1-0 | 1-60, 1-0 | 5 | 1 | 6 | 2 | 0 | 5 | 1 | 1 |
| | Totals | 5-100, 8-0 | 3-100, 4-0 | 15 | 14 | 19 | 7 | 3 | 16 | 8 | 4 |
| | Ranking[5] | | | 2 | 3 | | 2 | | | 3 | |
| D. Extension of analytical methods from information presently available to predict soil behavior, including seawater-seafloor interaction, inertial effects, etc. | INP[4] | 1-100, 3<20 | 2-100, 1-80 1-0 | 5 | 5 | 3 | 3 | 0 | 4 | 3 | 2 |
| | IP | 1-50 | 1-100 | 1 | 4 | 1 | 1 | 2 | 1 | 2 | 2 |
| | A | 1-100, 2<20 | 2>80 | 5 | 3 | 4 | 6 | 0 | 3 | 5 | 0 |
| | G | 2-100, 1-50 1-0 | 1-50, 1-0 | 4 | 2 | 6 | 1 | 1 | 3 | 3 | 1 |
| | Totals | 4-100, 6<20 | 2-0, 6>80 | 15 | 14 | 14 | 11 | 3 | 11 | 13 | 5 |
| | Ranking[5] | | | 2 | 3 | | 5 | | | 6 | |
| E. Consideration of transient pore pressures, seismic effects, and permeability. Are in situ measurements preferred? 28 yes 3 no | INP[4] | 4-0 | 3-100, 1-0 | 5 | 4 | 2 | 4 | 1 | 3 | 2 | 2 |
| | IP | 1-50 | | 2 | 3 | 2 | 2 | 0 | 2 | 3 | 0 |
| | A | 3-100, 1-0 | 1-0 | 4 | 4 | 6 | 3 | 0 | 6 | 2 | 0 |
| | G | 2-100, 1-0 | 1-0 | 3 | 2 | 5 | 1 | 1 | 3 | 2 | 1 |
| | Totals | 5-100, 6-0 | 3-100, 3-0 | 14 | 13 | 15 | 10 | 2 | 14 | 9 | 3 |
| | Ranking[5] | | | 3 | 4 | | 3 | | | 4 | |

| | yes | no |
|---|---|---|
| INP | 7 | 1 |
| IP | 5 | 0 |
| A | 8 | 2 |
| G | 8 | 0 |
| | 28 | 3 |

| | | Proprietary Documentation:[1] Your Organization %Available Responses[2] | Proprietary Documentation:[1] Your Organization %Unavailable Responses[2] | Check Timeliness: Your Organization Short Term: <5 yr Responses | Check Timeliness: Your Organization Long Term: >5 yr Responses | Indicate Priorities[1] 1=High 2=Intermed. 3=Low General Importance of Subject Responses[3] | | | Relationship to Specific Eng. Needs Responses[3] | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | 1 | 2 | 3 | 1 | 2 | 3 |
| F. Prediction of environmental loading at and just below the seafloor | INP[4] | 4<25 | 2-100, 2-75 | 5 | 4 | 1 | 4 | 2 | 2 | 2 | 3 |
| | IP | 1-50 | | 4 | 0 | 3 | 0 | 1 | 3 | 0 | 1 |
| | A | 2-100, 1-0 | | 4 | 4 | 4 | 5 | 0 | 2 | 5 | 0 |
| | G | 3-100 | 1-0 | 2 | 3 | 5 | 2 | 0 | 3 | 3 | 0 |
| | Totals | 5-100, 5<25 | 1-0, 4>75 | 15 | 11 | 13 | 11 | 3 | 10 | 10 | 4 |
| | Ranking[5] | | | 2 | 5 | | 6 | | | 7 | |
| G. Effects of geologic hazards; e.g., faulting, sand waves, gaseous soils, etc. | INP[4] | 1-100, 3<20 | 1-0, 2>80 | 3 | 6 | 2 | 3 | 1 | 3 | 2 | 2 |
| | IP | 1-75, 1-50 | 1-50 | 3 | 2 | 0 | 3 | 1 | 2 | 2 | 1 |
| | A | 2-0, 3>80 | 1-100, 2<20 | 4 | 5 | 4 | 2 | 3 | 5 | 2 | 1 |
| | G | 1-0, 3>80 | 1-20, 1-0 | 2 | 4 | 4 | 3 | 1 | 3 | 3 | 1 |
| | Totals | 8>75, 6<20 | 4<20, 3>80 | 12 | 17 | 10 | 11 | 6 | 13 | 9 | 5 |
| | Ranking[5] | | | 4 | 1 | | 7 | | | 5 | |

## II. Slope Stability

H. Means, methodology and procedures needed for solution of user requirements.

1. QUESTION: Instrument development (deficiencies and needs?)

ANSWERS

Industry: non-petroleum replies

- Pressurized samplers to retain in situ conditions.
- Sample disturbance is one of the major difficulties in marine soil investigation. Development of better sampling technique is required. The phenomenon of storm wave induced stress and pore pressure is poorly understood. Need instrumentation development to measure in-situ and storm wave-induced stress state and pore pressure. Reliable instrumentation for detecting bathymetry change, current rate, sediment transport rate, etc. is needed.
- Measurement of forces and deformations of foundation elements subjected to seafloor instabilities.
- Measurement of performance characteristics of soils subjected to environmental forces.

Industry: petroleum replies

- A real-time pore-pressure transducer.
- Development of practical devices for stress-strain-strength measurement.
- Development of practical devices for measurement of stress state at rest.
- A system which has the required amount of compliance to measure in-situ seafloor movements in response to wave pressures has yet to be developed.
- Same deficiencies as I.

Academic replies

- Need good underwater measurement systems.
- Many indirect means indicate considerable slope instability--trench scour, etc; good reliable long-term creep inclinometer-type sensors needed.
- Existing slope indicators and tiltmeters are inadequate for marine and remote access. Instruments for measuring rates of movement are needed for marine use.
- Need improved instruments for measuring deep (up to 300 ft penetration) soil movements and long-term (creep) movements. The availability of the Seaprobe makes this possibility very good.

Government replies

- Pore pressure devices with very fast response time. In situ stress measurement, especially lateral stresses. In situ permeabilities, including anisotropy. In situ shear strength, for all materials.
- Same as I (2 responses).
- We would like to monitor performance or behavior in the vicinity of pipelines or platforms.
- There is a general need for measurements of this nature (IIC) and development of high reliability instrumentation.
- Acoustic systems operable at continental slope depths which can provide high resolution data of sufficient quality to routinely deliniate not only major slump blocks but minor slump features as well.

Brief summary

There were a number of different responses under this category. These included a pressurized corer and better samplers; equipment for measuring stress-strain-strength, particularly under wave loading; piezometers having a fast response time; and instruments for measuring rates of movement, creap angle, slope, and tilt.

## II. Slope Stability

H. Means, methodology and procedures needed for solution of user requirements.

2. QUESTION: In situ measurements (deficiencies and needs?)

ANSWERS

Industry: non-petroleum replies
- Shear strengths, soil composition, gas volume and composition, pore pressures.
- Transient pore pressures and geometry of slips.
- Need field measurement programs in general.
- In-situ testing methods to measure deformation and strength characteristics of marine soil are badly needed.

Industry: petroleum replies
- See item 4.
- As stated in I.

Academic replies
- Need more projects so that more experience can be gained.
- In situ measurements of transient pore pressures are needed. In situ permeabilities are needed. Rates of motion are needed.
- Need site specific measurements of wave-induced movements. Need regional measurements of creep and other forms of mass movements.

Government replies
- Same as I. (3 responses)

Brief summary

In situ measurements of shear strength, transient pore pressure, gas volume and composition, permeability, rates of motion, and creep or mass movement are needed.

## II. Slope Stability

H. Means, methodology and procedures needed for solution of user requirements.

3. QUESTION: Analytical procedures and predictive models (deficiencies and needs?)

ANSWERS

Industry: non-petroleum replies

- Mudslide loading prediction techniques.
- Prediction of hydraulic loads on sliding geometry.
- Need results of additional field and laboratory programs before much additional work needed here.
- Offshore bottom instability is common everywhere; however, no substantial qualitation studies have been made. The following research studies are needed: (1) development of an understanding of the procedures of marine soil instability under various marine environments and loadings, (2) improvement of existing methods of slope stability analysis to account for various marine environments and loadings, and (3) new analytical procedure should be verified by actual case-history studies.

Industry: petroleum replies

- Evaluation of applicability and reliability of analytical procedures.
- Proprietary analytical models recently developed have not yet been evaluated.
- Most analytical procedures have been developed. The proprietary ones should make it into the literature soon.
- Need for "calibration" of mathematical models (extensive proprietary development). Additional effort here should be productive, particularly with regard to the triggering mechanism of ocean waves. Item F implies that loading at seafloor will be independent of seafloor response; in general, this will not be so.

Academic replies

- Static methods for analyzing and predicting slope stability are adequate, but dynamic approaches are still lacking.
- Analytical procedures to predict wave-induced seafloor movements still need to be improved.

Government replies

- Same as I, (2 responses)
- Three dimensional models are now under development for static slope stability. Such models are needed in soil-structure interaction problems as well because current methods are highly expensive and unreliable. Quantification of model biases would be useful as well as development of models that make an assumption and are closer to reality, in particular with respect to uniform safety factor value and rigid body motion.

Brief summary

Proprietary models developed by industry have not yet been evaluated by actual case-history studies.

## II. Slope Stability

H. Means, methodology and procedures needed for solution of user requirements.

4. QUESTION: Extended field observations, including monitoring (deficiencies and needs?)

ANSWERS

Industry: non-petroleum replies
- Details provided to public of known undersea slides and conditions prior to slips.
- Need field measurement programs in general.

Industry: petroleum replies
- Wave-data bottom-pressure, soil-displacement, pore-pressure and gas-pressure measurements.
- Programs in which wave degradation due to seabottom interaction will be quantified are presently under consideration by industry. The joint measurement of soil responses at selected points would be very advantageous if proper equipment were available.
- Shell is measuring slope using indicators. Data will probably be published within a short time. Know of no other field measurements offshore.
- Instrumentation of possible mudslide area to observe seafloor soil movements.

Academic replies
- Long-term measurements of movement are needed to separate creep and more rapid movements. Buildup of pore pressures before, during, and after movements are needed.
- See 2.

Government replies
- Need better feedback on predicted behavior prior to construction to observed behavior. New permanent displacement models for dynamic loading when liquefaction is not an issue are now in vogue. No field documentation of this type failure is currently available and would be extremely useful.
- Long-term mass movement of soils.
- Same as I.

Brief summary

Extended field observations needed include measurements of wave bottom-pressure response, soil displacement, and pore-water and pore-gas pressure; also, long-term measurements of creep and other mass movements.

## II. Slope Stability

I. QUESTION: Other (What are your most urgent short- and long-term needs, if not given above?)

ANSWERS

Industry: non-petroleum replies

- Long term: (1) Needed cooperation of oceanographic engineers, geologists, hydraulic engineers, and seismologists to completely understand the processes of ocean bottom instability, and (2) development of new innovated method to improve ocean bottom stability.
- Coherent design methodology for foundation elements is subjected to slope instabilities; note that design methodology is not equivalent to research results and analytical results. Field measurements of foundation and soil performance. This forms the basis for advancing the state-of-understanding and for potential advancements in current design methodology.

Industry: petroleum replies

- Geological and geophysical data.
- It is important to distinguish between data of a regional nature needed to identify potential slope stability problem areas from that data needed to understand the physical problem better.

Academic replies

- Ability to measure parameters (deformation, pore pressure, etc.) of dredge spoils before and during storms.
- Money!

Government replies

- Same as I.

Brief summary

See the replies from industry.

| III. Dynamic or Seismic Soil Properties and Behavior | | Proprietary Documentation:[1] Your Organization %Available Responses[2] | Proprietary Documentation:[1] Your Organization %Unavailable Responses[2] | Check Timeliness: Your Organization Short Term: <5 yr Responses | Check Timeliness: Your Organization Long Term: >5 yr Responses | Indicate Priorities[1] 1=High 2=Intermed. 3=Low General Importance of Subject Responses[3] | | | Relationship to Specific Eng. Needs Responses[3] | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| A. Measurement, collection, and dissemination of relevant geological, geophysical, and seismological data | INP[4] | 1-100, 2<30 | 2-100, 2>70 | 4 | 4 | 5 | 2 | 0 | 4 | 2 | 0 |
| | IP | 2<30 | 1-75 | 2 | 3 | 4 | 1 | 0 | 3 | 1 | 1 |
| | A | 3-100, 1-50 1-0 | 1-50, 1-0 | 8 | 1 | 6 | 2 | 0 | 3 | 4 | 0 |
| | G | 1-40, 5>90 | 2-10, 2-0 | 6 | 3 | 6 | 1 | 0 | 6 | 0 | 0 |
| | Totals | 9>90, 5<30 | 5<10, 5>70 | 20 | 11 | 21 | 6 | 0 | 16 | 7 | 1 |
| | Ranking[5] | | | 2 | 2 | | 2 | | | 2 | |
| B. Stress-strain behavior of soils under dynamic loading | INP[4] | 1-20, 2>80 | 2<20, 3>80 | 5 | 2 | 5 | 2 | 0 | 5 | 1 | 0 |
| | IP | 1<30 | 1-100 | 5 | 0 | 5 | 0 | 0 | 4 | 1 | 0 |
| | A | 2-100, 2<20 | 1-80, 1-0 | 7 | 2 | 7 | 2 | 0 | 5 | 2 | 0 |
| | G | 2-100, 1-50 1-0 | 1-50, 2-0 | 5 | 1 | 5 | 2 | 6 | 4 | 2 | 0 |
| | Totals | 6>80, 5<30 | 5<20, 5>80 | 22 | 5 | 22 | 6 | 6 | 18 | 6 | 0 |
| | Ranking[5] | | | 1 | 3 | | 1 | | | 1 | |

[1]Please see page 2, items 2 and 4, for a further description
[2]Number of responses-percentage available (or unavailable) some responses have been generalized.
[3]The number of responses in the three catagories (high, intermediate, and low) are listed from left to right.
[4]INP=industry, not petroleum; IP=industry, petroleum; A=academia; and G=government.
[5]The ranking designation is based solely on the total number of high priority responses. Should there be two or more identical totals, these are accorded equal ranking.

| | | Proprietary Documentation:[1] Your Organization %Avail-able Responses[2] | %Unavail-able Responses[2] | Check Timeliness: Your Organization Short Term: <5 yr Responses | Long Term: >5 yr Responses | Indicate Priorities[1] 1=High 2=Intermed. 3=Low General Importance of Subject Responses[3] | | | Relationship to Specific Eng. Needs Responses[3] | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| C. Emplacement of recording instrumentation in offshore locations for detecting both microseismic (for the location of faults) and strong motion activity | INP[4] | 2-0 | 3-100,1-0 | 3 | 4 | 3 | 3 | 1 | 2 | 3 | 1 |
| | IP | 1-100 | | 3 | 2 | 3 | 0 | 1 | 2 | 2 | 0 |
| | A | 3-100, 1-0 | 1-0 | 6 | 2 | 5 | 3 | 0 | 5 | 0 | 0 |
| | G | 3-100, 3<10 | 1-90, 3-0 | 2 | 6 | 2 | 3 | 1 | 2 | 1 | 2 |
| | Totals | 7-100, 6<10 | 5-0, 4>90 | 14 | 14 | 13 | 9 | 3 | 11 | 6 | 3 |
| | Ranking[5] | | | 3 | 1 | | 3 | | | 3 | |
| D. Measurement of free-field ground motion (for correlation with structural response) | INP[4] | 2-0 | 3-100,1-0 | 4 | 4 | 3 | 3 | 1 | 2 | 3 | 1 |
| | IP | 1-50 | 1-50 | 2 | 3 | 4 | 0 | 0 | 3 | 2 | 0 |
| | A | 3-100, 1-0 | 1-0 | 4 | 3 | 2 | 4 | 1 | 3 | 1 | 1 |
| | G | 2-100, 2-0 | 2-0 | 2 | 4 | 2 | 3 | 1 | 1 | 3 | 1 |
| | Totals | 5-100, 5-0 | 3-100,4-0 | 12 | 14 | 11 | 10 | 3 | 9 | 9 | 3 |
| | Ranking[5] | | | 4 | 1 | | 4 | | | 4 | |

## III. Dynamic or Seismic Soil Properties and Behavior

E. Means, methodology, and procedures for solution of user requirements.

1. QUESTION: Instrument development (deficiencies and needs?)

ANSWERS

Industry: non-petroleum replies

- Seismic on-bottom sensing device. Refer to the seafloor earthquake measurement system project.
- Development of rugged seismic recording instruments to sustain ocean environments is needed.
- A high and first priority need for this as well as the foregoing problem areas - instrument systems which are capable of making meaningful measurements of foundation and soil performance in the marine environment.

Industry: petroleum replies

- Model tests and laboratory devices capable of applying various dynamic cyclic stress paths.
- See Sandia Laboratory for state of art.
- Develop a standardized installation procedure for strong motion seafloor accelerometers to reduce cost of these installations.
- Free-field probe for mudline soil motion measurement, and the additional development of a resonant column method.

Academic replies

- Very little available. Better samplers and testing procedures needed.
- Need high frequency response for measurement of pore pressures. High response data acquisition equipment which will survive seismic movements and collect all data, not just samples of data.

Government replies

- We need in situ static and dynamic lateral stress, also dynamic pore-pressure measurements.
- Same as I.
- Strong support should be extended for instruments designed to be used in situ.
- Engineering instrumentation. Quick (minimum cost) assessment of the situation on which to base engineering decisions.
- Deep-water pore-pressure measurements under dynamic loading conditions.
- Development of a probe to obtain in situ densities of sands to 15 m (no proprietary information, urgency=1, priority=1).

Brief summary

Instrument development should include improved equipment for detecting seismic activity, piezometers having a high-frequency response, and measurement of the in situ density of sands,

## III. Dynamic or Seismic Soil Properties and Behavior

E. Means, methodology, and procedures for solution of user requirements.

2. QUESTION: In situ measurements (deficiencies and needs?)

ANSWERS

Industry: non-petroleum replies

- No network of strong-motion measurement stations is available in the offshore area. Need to set-up as many networks as possible, especially in the Atlantic and Pacific outer continental shelf.
- In general need the instruments first, then need to deploy them in meaningful field measurement programs.

Industry: petroleum replies

- Density and structure of sand and silt.
- In situ shear-wave velocity measurement device is presently being developed in proprietary research.
- At depth, earthquake measurements will eventually be essential after seafloor data are "routine".
- Shear wave velocity measurement.

Academic replies

- More difficult than under static conditions; cannot even be done on land yet.
- Need accelerometers to cover large range of frequencies for seafloor implantation.

Government replies

- We need in situ static and dynamic lateral stress, also dynamic pore-pressure measurements.
- Would like to monitor behavior of soils in the vicinity of construction, such as platforms and pipelines.
- Same as E1.
- Measures of in-situ density, shear modulus, pore pressure, and shear strength (no proprietary information, urgency=1, priority=1).

Brief summary

In situ instrumentation needed for the measurement of shear strength, density of sands and silts, dynamic pore pressure, shear-wave velocity, and lateral stress. Accelerometers having a wider frequency range and a networks of strong-motion stations on the outer continental shelf are also needed.

## III. Dynamic or Seismic Soil Properties and Behavior

E. Means, methodology, and procedures for solution of user requirements.

3. QUESTION: Analytical procedures and predictive models (deficiencies and needs?)

ANSWERS

Industry: non-petroleum replies

- Effects of seismic loading on the foundations of large structures.
- (1) Attenuation relationship for offshore area is practically non-existent and need research and development in this area, (2) development or improvement of methods to estimate the earthquake parameters (intensity, magnitude, acceleration level, etc.) in offshore area, and (3) analytical procedures and models to predict ground motion with respect to source mechanism, site condition, etc. are needed.
- Again, analytical procedures have outstripped our ability to correctly derive and interpret them.

Industry: petroleum replies

- See previous comments.
- Development of a general constitutive relation of soils under cyclic dynamic loading.
- Wait for field data, the state of art doesn't need another procedure.
- Prediction of surface wave soil motions (considerable proprietary work has been done).
- Prediction of body wave soil motions (reports are available under technical information license).

Academic replies

- Not completely familiar with what is available in this area.
- Analytical techniques used for onshore prediction of seismic response are probably adequate for offshore application--the greatest need is for better material properties.

Government replies

- We need a good effective-stress model to predict liquefaction.
- Same as I. (2 responses)
- Capability to predict holding capacity of anchors under repeated loads (urgency=1, priority=2).

Brief summary

Emphasis should be placed on the data collection of material properties and on the derivation and interpretation of these data rather than on the further development of models. There is also a need to improve the capability of predicting the dynamic holding capacity of anchors.

III. Dynamic or Seismic Soil Properties and Behavior

E. Means, methodology, and procedures for solution of user requirements.

4. QUESTION: Extended field observations, including monitoring (deficiencies and needs?)

ANSWERS

Industry: non-petroleum replies

- Discussed previously.

Industry: petroleum replies

- A cooperative program among offshore operators exchanging seismic monitoring data and information.
- Ground motion, transient pore-pressure measurements.
- Field measurements to determine correlation between bedrock seismic excitation and resultant surface ground motion would provide a valuable complement to current work.

Academic replies

- Discussed previously.

Government replies

- We need more case histories to evaluate our present design and analysis techniques.
- Same as I. (2 responses)
- Examine embedded anchor response (urgency=1, priority=2).

Brief summary

See responses under E4, above.

## III. Dynamic or Seismic Soil Properties and Behavior

F. QUESTION: Other (What are your most urgent short- and long-term needs, if not given above?)

ANSWERS

Industry: non-petroleum replies

- Correlations between static and dynamic properties of soil deserve more attention.
- Discussed in foregoing sections.

Industry: petroleum

No responses.

Academic

No responses.

Government replies

- Urgently need an in situ liquefaction test and in situ pore-pressure and stress-strain measurement tools.
- Same as I.

Brief summary

See responses under F, above.

## PART TWO: Soil-Structure Interaction Seafloor Information Needed for Engineering Purposes

Preamble:

Soil-structure interaction is interpreted in its broadest sense to include environment-structure interaction, foundation-soil interaction, and structure-foundation interaction. Environment-soil interaction problems would be included under Part One research. Specific methodology has not been recommended; it is best defined when relevant projects are proposed. For example, one suggested method would be to under-design deliberately test structures to induce foundation failures caused by small cyclic wave loads, the results of which could be observed under favorable sea conditions.

The justification for involvement of other organizations in soil-structure interaction problems includes the following reasons:

1. To promote the public availability of data.
2. To train, educate, and provide experience for personnel in other organizations who must interact with industry.
3. To insure that the collection of the basic natural or environmental information, previously described under Part One, is pertinent and relevant to engineering needs.
4. To provide guidance to regulating authorities in technical areas where adequate information is lacking.
5. To enable an input for the design of structures, such as military installations.

Examples of existing cooperative programs include:

1. Geotechnical measurement project--bottom instrumentation system (Sandia Laboratories, DOE, USGS, OOE/NOAA).
2. Behavior of clay soils under earthquake and wave loading (Shell Development Co., OOE/NOAA, USGS, DOE).
3. Undersea structures inspecting/testing/monitoring (Busby Associates, OOE/NOAA, DOE, USGS).

I. Two programs are proposed:

A. To initiate or participate in funding engineering research investigations designed to provide for the analysis and design of soil-structure interaction problems where adequate methods do not currently exist.

B. To initiate or participate in cooperative industry and other organization programs of field observation and experiment, including instrumentation of structures where appropriate.

| Examples of cooperative industry-other organization soil-structure interaction problems, which are relevant to existing engineering needs that might be supported include: | | Proprietary Documentation:[1] Your Organization %Available Responses[2] | Proprietary Documentation:[1] Your Organization %Unavailable Responses[2] | Check Timeliness: Your Organization Short Term: <5 yr Responses | Check Timeliness: Your Organization Long Term: >5 yr Responses | Indicate Priorities[1] 1=High 2=Intermed. 3=Low General Importance of Subject Responses[3] | | | Relationship to Specific Eng. Needs Responses[3] | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. Effects of both general and localized liquefaction, caused by waves or by seismic loading, on the capacity of footings and piles | INP[4] | 2>75, 3<10 | 1-25, 2>90 | 6 | 2 | 7 | 1 | 0 | 7 | 0 | 0 |
| | IP | 1<50 | | 3 | 2 | 3 | 1 | 0 | 2 | 2 | 1 |
| | A | 2-100, 1-0 | 1-0 | 8 | 2 | 7 | 0 | 0 | 6 | 1 | 1 |
| | G | 4-100, 1-0 | 1-90 2-0 | 6 | 1 | 6 | 2 | 1 | 4 | 3 | 0 |
| | Totals | 8>75, 5<10 | 3-0, 3>90 | 23 | 7 | 23 | 4 | 1 | 19 | 6 | 2 |
| | Ranking[5] | | | 1 | 6 | | 1 | | | 1 | |
| 2. Cyclic behavior of gravity structures founded on different types of soils. | INP[4] | 2-100, 3-0 | 1-100, 1-50 2-0 | 6 | 2 | 4 | 4 | 0 | 5 | 2 | 0 |
| | IP | 1<50 | | 4 | 1 | 0 | 4 | 0 | 1 | 3 | 1 |
| | A | 1-100, 1-0 | 1-0 | 7 | 1 | 5 | 2 | 0 | 5 | 2 | 0 |
| | G | 2-100, 2<15 | 1-85, 1-0 | 4 | 2 | 4 | 3 | 1 | 2 | 4 | 1 |
| | Totals | 5-100, 6<15 | 4-0, 2>85 | 21 | 6 | 13 | 13 | 1 | 13 | 11 | 2 |
| | Ranking[5] | | | 3 | 7 | | 4 | | | 4 | |

[1] Please see page 2, items 2 and 4, for a further description.
[2] Number of responses-percentage available (or unavailable) some responses have been generalized.
[3] The number of responses in the three catagories (high, intermediate, and low) are listed from left to right.
[4] INP=industry, not petroleum; IP=industry, petroleum; A=academia; and G=government.
[5] The ranking designation is based solely on the total number of high priority responses. Should there be two or more identical totals, these are accorded equal ranking.

[1] Please see page 2, items 2 and 4, for a further description.
[2] Number of responses-percentage available (or unavailable) some responses have been generalized.
[3] The number of responses in the three catagories (high, intermediate, and low) are listed from left to right.
[4] INP=industry, not petroleum; IP=industry, petroleum; A=academia; and G=government.
[5] The ranking designation is based solely on the total number of high priority responses. Should there be two or more identical totals, these are accorded equal ranking.

| | | Proprietary Documentation:[1] Your Organization | | Check Timeliness: Your Organization | | Indicate Priorities[1] 1=High 2=Intermed. 3=Low | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | %Available Responses[2] | %Unavailable Responses[2] | Short Term: <5 yr Responses | Long Term: >5 yr Responses | General Importance of Subject Responses[3] | | | Relationship to Specific Eng. Needs Responses[3] | | |
| 3. Settlement of present divergent view points on axially-loaded pile analysis and design ("rational" effective stress or pseudo effective stress approach versus empirical correlation methods). | INP[4] | 2>90, 3<25 | 2>75 | 5 | 3 | 4 | 4 | 0 | 5 | 2 | 0 |
| | IP | 1<50 | 1-100 | 3 | 2 | 3 | 1 | 0 | 2 | 0 | 2 |
| | A | 1-100, 2<25 | 1-100, 1-75 1-50 | 4 | 4 | 3 | 4 | 1 | 3 | 3 | 1 |
| | G | 2-100, 1-50 | 1-50, 1-0 | 1 | 5 | 1 | 4 | 2 | 1 | 2 | 3 |
| | Totals | 5>90, 6<25 | 2-50, 1-0, 5>75 | 13 | 14 | 11 | 13 | 3 | 11 | 7 | 6 |
| | Ranking[5] | | | 5 | 2 | | 6 | | | 6 | |
| 4. Prediction of the performance of laterally-loaded piles in fine sands and silts (static, slow cyclic, and dynamic or seismic loadings). | INP[4] | 1-100, 2-50 2<10 | 1-50, 2>90 | 7 | 1 | 7 | 1 | 0 | 6 | 1 | 0 |
| | IP | 1-100, | | 5 | 2 | 1 | 3 | 0 | 2 | 1 | 2 |
| | A | 1-100, 2-0 | | 6 | 3 | 4 | 3 | 0 | 4 | 2 | 1 |
| | G | 3-100, 2<25 | 2-0 | 4 | 4 | 2 | 3 | 2 | 2 | 2 | 2 |
| | Totals | 6-100, 5<25 | 4-0, 3>75 | 22 | 10 | 14 | 10 | 2 | 14 | 6 | 5 |
| | Ranking[5] | | | 2 | 4 | | 2 | | | 3 | |

| | | Proprietary Documentation:[1] Your Organization %Available Responses[2] | Proprietary Documentation:[1] Your Organization %Unavailable Responses[2] | Check Timeliness: Your Organization Short Term: <5 yr Responses[2] | Check Timeliness: Your Organization Long Term: >5 yr Responses | Indicate Priorities[1] 1=High 2=Intermed. 3=Low General Importance of Subject Responses[3] | | | Relationship to Specific Eng. Needs Responses[3] | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 5. Large-displacement lateral-load performance of pile groups (static, slow cyclic, dynamic or seismic loadings) | INP[4] | 1-100, 1-50 3-0 | 1-100,1-50 1-0 | 6 | 3 | 6 | 2 | 0 | 6 | 1 | 0 |
| | IP | 1<25 | | 2 | 3 | 2 | 0 | 1 | 3 | 1 | 1 |
| | A | 1-100, 1-50 2-0 | 1-50, 2-0 | 7 | 1 | 4 | 3 | 0 | 7 | 1 | 0 |
| | G | 2-100, 2<10 | 1-90, 1-0 | 3 | 4 | 2 | 3 | 2 | 1 | 3 | 2 |
| | Totals | 4-100, 8<25 | 4-0,2-50,2>90 | 18 | 11 | 14 | 8 | 3 | 17 | 6 | 3 |
| | Ranking[5] | | | 4 | 3 | | 3 | | | 2 | |
| 6. Estimation of allowable lateral and axial pile support in calcareous sands, particularly those composed of crushable tests or shells | INP[4] | 1-100, 1-50 3<10 | 1-100,1-50 1-0 | 7 | 1 | 4 | 3 | 1 | 4 | 2 | 1 |
| | IP | 1-0 | 1-0 | 1 | 4 | 0 | 1 | 3 | 0 | 1 | 4 |
| | A | 1-100, 2-0 | 2-0 | 3 | 4 | 2 | 1 | 3 | 3 | 2 | 2 |
| | G | 3-100, 1-40 1-0 | | 2 | 5 | 1 | 4 | 2 | 1 | 4 | 1 |
| | Totals | 5-100, 7<10 | 1-100,6-0 | 13 | 14 | 7 | 9 | 9 | 8 | 9 | 8 |
| | Ranking[5] | | | 5 | 2 | | 8 | | | 8 | |

| | | Proprietary Documentation:[1] Your Organization %Available Responses[2] | Proprietary Documentation:[1] Your Organization %Unavailable Responses[2] | Check Timeliness: Your Organization Short Term: 5<yr Responses | Check Timeliness: Your Organization Long Term: 5>yr Responses | Indicate Priorities[1] 1=High 2=Intermed. 3=Low General Importance of Subject Responses[3] | | | Indicate Priorities[1] 1=High 2=Intermed. 3=Low Relationship to Specific Eng. Needs Responses[3] | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | 1 | 2 | 3 | 1 | 2 | 3 |
| 7. Criteria for the design of mudslide-resistant structures. | INP[4] | 2-100, 3<10 | 1-0, 2>90 | 5 | 3 | 3 | 4 | 1 | 4 | 2 | 1 |
| | IP | 1<30 | 1-100 | 3 | 2 | 2 | 2 | 0 | 3 | 2 | 0 |
| | A | 1-100, 2-0 | 1-100, 1-0 | 7 | 1 | 3 | 4 | 0 | 5 | 2 | 0 |
| | G | 2-100, 1-50 | 1-50, 1-0 | 3 | 3 | 2 | 4 | 1 | 1 | 2 | 3 |
| | | 1-0 | | | | | | | | | |
| | Totals | 5-100, 6<10 | 3-0, 4>90 | 18 | 9 | 10 | 14 | 2 | 13 | 8 | 4 |
| | Ranking[5] | | | 4 | 5 | | 5 | | | 5 | |
| 8. Probabilistic design methods and risk analyses | INP[4] | 1-100, 3<30 | 2-100, 1-70 | 2 | 7 | 1 | 5 | 2 | 2 | 3 | 2 |
| | IP | 1-100, 1<30 | | 1 | 3 | 1 | 1 | 2 | 0 | 1 | 2 |
| | A | 2-100, 1-0 | 1-0 | 3 | 4 | 2 | 4 | 0 | 4 | 2 | 0 |
| | G | 2-100, 1-60 | 1-40, 1-0 | 4 | 2 | 4 | 3 | 0 | 2 | 3 | 1 |
| | | 1-0 | | | | | | | | | |
| | Totals | 6-100, 6<30 | 2-100, 2-0 | 10 | 16 | 8 | 13 | 4 | 8 | 9 | 5 |
| | Ranking[5] | | | 6 | 1 | | 7 | | | 7 | |

9. QUESTION: Other (What are your most urgent short- and long-term needs, if not given above?)

ANSWERS

Industry: non-petroleum replies

- (1) Need a reliable analysis procedure (method for soil-pile-water-structure interaction under various dynamic loading conditions (earthquake, storm wave, current and wind, etc.), (2) a reliable constitutive relation for marine soils under dynamic loading conditions; (3) case history studies (and performance) of various offshore structures under dynamic loading condition, and a (4) critical review of current analytical methods of soil-structure interaction analysis for offshore structures.
- Of the two parts (Seafloor Information and Soil-Structure Interaction), the current important design engineering questions lie in soil-structure interaction; however, the current important research engineering questions lie in the Seafloor Information part. Thus, short-term high priorities generally lie in the soil-structure interaction area (current design applications) while long term high priorities lie in the seafloor information area (future design applications).
- We have no documentation that has not appeared in applications for regulatory approval.

Industry: petroleum replies

- Construct a scale model (perhaps 1/5 scale) instrumented pile in seismically active areas, not necessarily offshore, and monitor through earthquakes.
- Development of numerical solution techniques for determining soil-structure interaction under static and dynamic loadings.

Academic replies

- A means of evaluating the stability of buried pipelines is needed.

Government replies

- The question of scour effects often arise (not urgent, a continuing question from site to site).
- Improved constitutive properties used as input to soil structure interaction analytical and computer solutions.
- Holding capacity of direct embedment anchors in any ocean-bottom material under long-term loadings, either static or dynamic (proprietary - none, urgency=1, priority=1).

Brief summary

Variable responses, not separately summarized.

## PART THREE: Seafloor Engineering Data Banks and Retrieval Systems

Preamble:

The acquisition and distribution of environmental data of relevance to seafloor engineering is important. Such information should be made available to the general public in many different forms. It is assumed that this key function would be extended to cover Part One and Part Two research whenever appropriate. The latest technology and the most advanced data management system should be utilized to facilitate access to the information in one or more centralized facilities.

| | strongly | weakly | not at all |
|---|---|---|---|
| INP | 5 | 3 | 1 |
| IP | 2 | 2 | 0 |
| A | 7 | 1 | 2 |
| G | 6 | 1 | 0 |
| Totals | 20 | 7 | 3 |

Do you agree with this statement: Totals 20 strongly 7 weakly 3 not at all
If not, how shall data acquisition and distribution be effected?

Industry: non-petroleum
- What is "general public?" Agree sentence 1, if word environmental omitted. Disagree with sentences 2 & 3. Generally agree with sentence 4.
- I support strongly the need for centralized data of the simpliest reduced form. A quick search shows me that one can find sophisticated data in literature but can make no use of it because key information like design for us are unavailable. So I support the need for reporting design conditions, coupled with reduced data using prescribed procedures rather than opting for emphasis on the data gathering and management system.
- To make all data available to all persons would encourage misapplication, and would be very expensive.
- A combination of the existing systems and an effective centralized system. Public and private research have their respective roles. In the past, their interaction has been frequently ineffective and inefficient. Thus, a focus should be toward improving the technology transfer and coordination of these two activities (such as this particular effort).

Industry: petroleum
- Present methods of storing and retrieving such data appear to be largely adequate.
- Do not develop new data banks. Use existing data banks such as NOAA's NODC.
- Agree, except that an extension to cover research may not be practical in all cases where proprietary implications are involved.

Academic

- Do not agree because of cost. Worthwhile information reaches the interested people through publications. Some of the generated data are not worth keeping. Who shall be the judge of what to keep? Other scientific fields of importance do not have data acquisition. Systems like Geodex will be sufficient.
- Agree generally with the concept, but feel that it is completely impractical. Best way to obtain data is still from publications and personal contacts. Except for routinely gathered data (i.e., weather and tide data), data banks across various organizations have never been successful. Everyone wants their data to be proprietary and all other data to be nonproprietary.
- Publications in journals, conference proceedings, etc.

Government

- I will leave to the practicing engineers this question. As a research geologist-geophysicist I would rarely use such a system in my present work.
- Frankly, I think this is an extremely nebulous and poorly worded leading statement. It is impossible for a reader to disagree with the first sentence. However, it is not clear to me that a National Program in the geotechnical area is required. I much prefer a pay-as-you-go federal and industry funded approach. This insures that money is spent on relevant activities. As far as data storage goes, I would only support centralized facilities if they were in a Government Agency, such as NOAA. My experience with academic and industry data custodians has been uniformly poor.
- Can't the NGS-T Data Center handle this?
- Note that we specify one facility. We believe the first effort should be to provide this service through NOAA's Environmental Data Service.
- Data and information obtained through federal funded studies and projects would be required to go to a data bank available to the public at a nominal handling fee. Non-proprietary information from industry could also be placed in the data bank. All data are to be available under the Freedom of Information Act.

I. Seafloor Engineering Data Acquisition and Retrieval (deficiencies and needs?)

Industry: non-petroleum

- To convince consultants to participate will be virtually impossible to do.
- Central data center is not available. Need set-up. (High priority)
  Oil companies have a lot of invaluable information. They should be persuaded to make their data available. (Intermediate priority)
- Need standardization for marine work both in methods and reporting units. (High priority)
- Dissemination of data from offshore facilities previously collected by private industry. (High priority)
- An inventory of seafloor sediments by location and type would be helpful. (High priority)

- Instrumentation systems capable of making the measurements needed. (High priority)
  Information systems capable of coordinating and directing efforts. (Intermediate priority)
  Field instrumentation projects. (High priority)
  Data distribution and technology transfer systems. (Intermediate priority)
- Centralized sources or facilities for data; standardization of measurement systems and techniques. (High priority)

Industry: petroleum
- Raw data banks.
  A newsletter advising of new cooperative projects.
  Publish post mortem evaluation of failures such as that now done for aircraft failures.
- Geological and geophysical data. (High priority)
  Basic soil information. (Intermediate priority)
  Seismological data. (Low priority)
- Soil Properties with depth if possible. (High priority)
  Geologic Hazards. (High priority)
  Shallow Seismic data. (Intermediate priority)
- Need: Data acquisition should involve those who will be both the developer of the technology in the area in which it's used and to a lesser extent the user himself. For "routine" data acquisition, I don't have the same concern. (High priority)

Academic
- All of the good data are proprietary with the oil companies and is unavailable or cannot be quoted, so how can there be a data bank?
- Main deficiency: data from atmosphere, water column, bottom and subbottom at some point and time.
- There is a need to systematically acquire and store existing data from publications. (Intermediate priority)

Government
- There is a lack of data for most of the areas in which we work because of our lack of affiliation with a major industry. Navy jobs are usually small, and I think it correct that we gather and pay for data as it is required. The crude data in the survey literature gets us started, and we prefer to do our own fine grain survey work. This insures that our design decisions are based on known data quality--we establish the risk versus data quality trade-off for each individual job.
- Standardized reporting procedures and a centralized data bank.
- Existence of data bank needs to be publicized. Means of encouraging researchers to contribute is needed (visit by representative of EDS to principal researchers perhaps). Format for case histories and environmental interaction studies needs to be developed. (Intermediate priority)

APPENDIX C

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☆ U. S. GOVERNMENT PRINTING OFFICE : 1978 261-238/258

NOAA--S/T 78-413